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RELATIONSHIP OF FISH HABITAT TO RIVER FLOW IN THE GUNNISON RIVER

Final Report

March 1998

U. S. Fish and Wildlife Service
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RELATIONSHIP OF FISH HABITAT TO RIVER FLOW IN THE GUNNISON RIVER

Colorado River Recovery Implementation Program
Project Number 47

Final Report

March 1998

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Executive Summary

This study described relationships between fish habitat and river flow in the Gunnison River. These relationships will be used in conjunction with data collected in a variety of other studies to make flow recommendations for operation of the Aspinall Unit in the upper Gunnison River. The Aspinall Unit is a series of three reservoirs (Blue Mesa, Morrow Point, and Crystal) that were completed by the Bureau of Reclamation between 1966 and 1976. These reservoirs have had a significant impact on timing and magnitude of river flows within critical habitat for two endangered fishes — Colorado squawfish *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*. Reoperation of the Aspinall Unit will contribute to recovery of these two species in the Gunnison River.

We used a combination of airborne videography and mapping of surface habitats to quantify surface area of 11 macro-habitat types at 5 study sites under 7 river flows. These flows ranged between a low of 981 cfs (the lowest flow in the Gunnison River during the study) to a high of 15,800 cfs. In addition to habitat mapping, cross-channel bed profiles were surveyed annually at each study site to monitor changes in the river channel. Habitat mapping was also supplemented with staff gauges placed at important bottomland sites to determine when over-bank flooding occurred. The study extended over a 4-yr period that saw peak flows of 20,500 cfs in 1993, 6,040 in 1994, 17,300 in 1995, and 7,670 in 1996.

Maintenance and restoration of flooded-bottomland habitats is an important component of the Recovery Program. In the Gunnison River, most of this bottomland habitat occurs near Delta, Colorado. Over-bank flooding in the Delta area began at flows as low as 6,000 cfs, with considerable flooded habitat available at 8,000 cfs. Area of flooded habitat increased as discharge increased; however, low-velocity deep-water habitats were maximized at about 13,000 cfs in the primary floodplain study site.

A base-flow recommendation already exists for the lower Gunnison River. A minimum of 300 cfs is required to provide a migration corridor in a 2.3-mi-long reach between the Colorado River and the Redlands Diversion Dam where a fish passage structure has recently been completed. Combined with a 750 cfs water right held by Redlands, that recommendation translates into a base flow of about 1,050 cfs in the Gunnison River above the dam. The lowest flow we studied approximates the base flow mentioned above and that flow provided a mixture of habitats preferred by Colorado squawfish — pools, eddies, and slow runs.

Maintaining habitat complexity necessary for a healthy river environment requires regular scouring and bar building along the river channel. In this study, some scouring and deposition occurred in all years, but major channel modifications occurred more often in high-runoff years than in low-runoff years. Further, material that accumulated in pools during low-runoff years was removed during high-runoff years.

The habitat relationships described above should be used in conjunction with data collected during other studies and basic life history information for the two endangered fishes to make flow recommendations for the Gunnison River.

Any flow recommendations implemented for the Gunnison River should be accompanied by a monitoring program to assess the results. The evaluation should include options for monitoring channel change and area of flood-plain habitat, as well as response by the native fish community.

Introduction

The Gunnison River is historic habitat for Colorado squawfish *Ptychocheilus lucius* and razorback sucker *Xyrauchen texanus*. Anecdotal accounts from long-time residents suggest that both species were common in the river during the early and middle parts of this century (Quartarone 1995). However, a variety of human-induced impacts to the Gunnison River have substantially reduced these two species' abundance in the river. In addition to other impacts, Redlands Diversion Dam — constructed in 1917 at river mile (RM) 3 — prevented upstream movement of fish from the Colorado River and isolated fish in the Gunnison River from the rest of the river basin. Relatively few Colorado squawfish or razorback sucker remained in the river above Redlands Diversion when organized sampling efforts began in the 1970's. A total of six Colorado squawfish were collected from the Gunnison River between 1979 and 1983 (Valdez et al 1982; Wick et al. 1985). Three razorback suckers were collected from the river near Delta, CO at about the same time (Holden et al. 1981). Intensive sampling by Burdick (1995) between 1992 and 1994 yielded five Colorado squawfish captured in the river above Redlands Dam. Four others were positively sighted but could not be captured. No razorback sucker were captured by Burdick (1995). However, the Gunnison River from its mouth to its confluence with the Uncompahgre River was declared Critical Habitat in 1994 (USFWS 1994) based on historic distribution of the two species.

Three reservoirs (Blue Mesa, Morrow Point, and Crystal), composing the Aspinall Unit of the Colorado River Storage Project, were completed by the Bureau of Reclamation (Reclamation) in the upper Gunnison River between 1966 and 1976. These reservoirs were built upstream of habitat occupied by the endangered fishes and have a substantial impact on critical habitat of these species. The largest impact was changes in timing and magnitude of river flows within critical habitat (McAda and Kaeding 1991).

Although the Aspinall Unit substantially altered habitat occupied by the endangered fish, authorization and construction of the project occurred before passage of the Endangered Species Act of 1973, as amended. However, the Fish and Wildlife Service (Service) and Reclamation recently agreed to initiate consultation on effects of operation of the Unit on the endangered fishes. This effort was one of several coordinated studies initiated to evaluate those impacts and make recommendations to improve habitat for the endangered fishes in the Gunnison River. This study was done to document changes in macro habitat available to fish with changes in river flows. This information along with biological and physical data collected during previous and concurrent studies will be used to assess the impacts of the Aspinall Unit on the endangered fishes.

All fishes require a variety of habitats throughout the year to complete their life cycle. Peak flows in spring reconfigure the channel and provide flooded bottomlands which are important for allochthonous input to the system (Stanford et al. 1996; Poff et al. 1997). Flooded bottomlands also provide resting areas for adult fish escaping fast water in the main channel and important rearing habitats for YOY fishes (e.g., Wydoski and Wick 1998). In the Colorado River basin, adult Colorado squawfish and razorback sucker use off-channel habitats extensively in spring (Osmundson et al. 1995). The low velocity and warmer water temperatures in off-channel habitats are hypothesized to assist with growth and gonad maturation during a time when river temperatures are still cool and high water velocities require increased energy expenditures. Flooded bottomlands are especially important to growth and survival of larval razorback suckers (Wydoski and Wick 1998; Modde et al. 1995). When flooded bottomlands are not available, other low-velocity habitats such as slow runs, pools, eddies, backwaters and flooded vegetation along the shoreline provide refuge from fast water in mid-channel habitats. However, these other habitats do not substitute for the productivity of flooded bottomlands (Wydoski and Wick 1998).

Except for a transition period before and after spring runoff, base flows occur through most of the year (summer, fall, winter). Colorado squawfish preferred pools, eddies, and backwaters at moderate base flows and slow runs at very low base flows in the upper Colorado River (Osmundson et al. 1995). Razorback suckers also used pool and slow-run habitats during base flows. High-velocity or shallow habitats are generally not utilized except for brief periods. However, shallow riffles or cobble bars are used for spawning by both species (Tyus and Karp 1990; Tyus 1991). Backwaters are important habitats for young of both species (Tyus and Haines 1991; Gutermuth et al. 1995). Throughout the year many different habitats are used by different life stages of the two species. Providing a variety of usable habitats in the appropriate spatial and temporal relationship will be important to recovery of these two endangered fishes in the Gunnison River. This study described the relationship between fish habitat and river discharge in the Gunnison River.

The overall goal of this study was to quantify changes in fish habitat in the Gunnison River with changes in river flow and to use that information to assist with making flow recommendations for operation of the Aspinall Unit. The objectives of the study were:

1. Use a combination of airborne videography and ground truthing to quantify macro habitat at different flow levels.

2. Use channel cross sections to describe changes in river morphology over time.

3. Use the information collected to: (a) assist with the process of making year-round flow recommendations for the Gunnison River and (b) assist with identification of areas that might be appropriate for habitat-improvement projects.

Methods

Study Area

Five study sites were selected within the portion of the Gunnison River currently occupied by Colorado squawfish (Figure 1; Table 1). The study sites varied from 0.5 to 1.6 mi in length and were selected to represent the range of macro habitats available in the Gunnison River. Two sites (1, 2) were selected because of Colorado squawfish use documented by Burdick (1995) and one site (3) was chosen because general features of the site resembled reaches of the Green or Yampa rivers known to be spawning sites used by Colorado squawfish. One site (4) was chosen because it was also being used in a study conducted jointly by Reclamation and the U.S. Geological Survey (USGS) and the last site (5) was chosen because it represented floodplain habitat. The joint Reclamation-USGS study investigated flows necessary to move sand, silt, and larger particles from the bed of a regulated river (Milhous in press). The five sites composed a relatively small portion of the Gunnison River, but represented all macro habitats found there.

Habitat Mapping

Reclamation videotaped the Gunnison River from a helicopter flying along the river corridor at a constant elevation of 2,000 ft. A continuous image of the river was acquired from its mouth to Austin, Colorado (65 mi) using a Sony DXC M7 CCD video camera with a 12:1 zoom lens set at full wide angle. The imagery was recorded on a Sony 3/4-in VO 8800 Umatic SP recording deck. Most of the river was covered by a single upstream pass. However, the wide river channel and extensive floodplain in Escalante State Wildlife Area (SWA; Site 5) required three different passes to capture the different river channels and all floodable areas on the video. A total of seven flights were made at river discharges ranging from 981 to 15,800 cfs. The entire study area was videotaped in 1 day at each flow level.

Surface habitat was mapped by a ground crew at the same time as the helicopter flight. However, it took the ground crew 2 days to map all five study sites at each river flow. Usually the four lower sites were mapped on the first day and the much more complicated Site 5 was mapped on the second day. The senior author did all habitat mapping to ensure consistent habitat classification among study sites and river flows (Roper and Scarnecchia 1995). The water surface at each of the

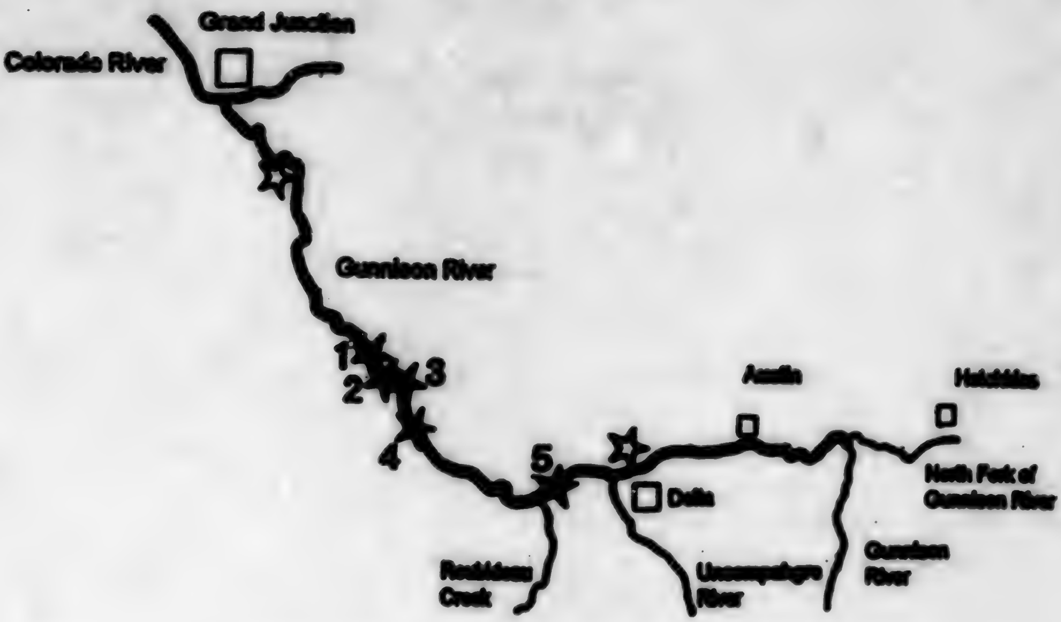

Figure 1. — Location of study sites (★) in the Gunnison River. USGS river gauges are indicated with ☆.

Table 1. — Location of study sites in the Gunnison River.

Study Site	Location (River Mile) Study Site	Location (River Mile) Transect	General Description
1	31.8 – 32.4	31.9 32.2	Straight, single channel. The simplest study site. Documented Colorado squawfish use.
2	33.6 – 34.1	33.7 34.0	Pool and eddy complex with documented Colorado squawfish use.
3	34.3 – 34.9	34.5 34.7 34.9	Island complex with two side channels at most flows. Second most complex site.
4	37.4 – 38.3	37.5 37.6	BR, USGS flushing flow study site (Milhous, in press). Habitat mapping was done in the lower 0.5-mi section of the site. Selected for the flushing flow study because it was thought to be representative of Colorado squawfish spawning sites in other rivers.
5	50.7 – 52.3	51.1 51.7 52.2	Wide, floodplain complex within Escalante SWA near Delta Colorado. The most complex of all the sites.

study sites was broken into 11 habitat categories — fast run, slow run, rapid, riffle, eddy, pool, slack water, backwater, flooded vegetation, sheet flow, and flooded bottomland (Table A-1; modified slightly from Osmundson et al. 1995). All available habitats were sketched on video prints from earlier flights at similar flows. Mapping was usually done from a boat moving through the study area, but occasionally was done from a prominent point on the shoreline with a good view of the river. Complete maps of the main river channel were made on all occasions. However, the extensive floodplain at Escalante SWA was impossible to map completely at high discharges because the water covered a large area that could not be covered in the boat or on foot and could not be seen from a prominent point on the bank. General outlines of the flooded area were sketched in the field and then filled in more completely using the video from that day. The more general habitat types such as sheet flow and flooded bottomland were used in those cases.

After the flight was completed, videotapes were sent to the laboratory where overlapping frames of each study reach were digitized ('grabbed') using PC-based image processing software (TNT Mips version 5.3; Microimages, Inc, Lincoln, NE). High resolution color prints were made of the digitized frames and sent to the senior author. Field maps were transferred to the color prints taken on the day (± 1) of mapping. Habitat boundaries were drawn on the final maps as they were sketched in the field. Adjustments to habitat boundaries were made when those boundaries were clearly evident on the new prints. Boundaries of flooded areas outside the main channel were further delineated with the help of the current video print. Completed maps were then sent to the junior author for further analysis.

In the laboratory, the individual frames for each site were tied together into one large mosaic of the reach. The mosaics for each site were set to a common scale by scanning a 1:12,000 scale color infrared (cir) photograph into the computer using a Howtek Scanmaster three-color scanner (300 dpi). Once in digital form, the scale of the scanned photo was set at 1:12,000. Each video mosaic was then displayed on the computer screen beside the scanned cir photo and common landmarks (e.g., prominent trees, rocks, bridges, etc) between the two images were tagged and saved. A minimum of 20 points distributed throughout the image were selected in this process. Each control point was then given an exact georeference position which equalized the scale for the different video flights. After all the video mosaics were transformed to the same scale, habitat boundaries from the field maps were digitized as a vector overlay to the transformed video mosaic. Digitized habitat maps were carefully reproduced and compared with field maps and live videotape for accuracy. Surface area for each habitat type was calculated by summing area within the polygons delineating the 11 habitat categories.

Channel Cross Sections

Two or three permanent cross-channel transects were established at each of the five study sites. Reinforcing-rod head pins were placed on both sides of the river as permanent marks for the transect. Complete cross sections were surveyed in late summer or early fall when water levels were low and surveying could be more easily done. A marked, kevlar cable was stretched between two fence posts at either end of the transect. Surface elevations (± 0.1 ft) were measured along the cable using a surveyor's level and a 25-ft-long level rod. Ground and river-bed elevations were usually taken at 10-ft intervals or at significant changes in slope, whichever was smaller. However, elevations on gradual slopes away from the river channel were taken at 20-ft intervals. Water surface elevations were measured on both sides of bars, islands, and the main channel along the transect. Also, water surface elevation was measured at one end of each transect every time that surface habitat was mapped. Water velocity and substrate size were not measured.

Bed profiles were plotted to display changes in bed elevation between measurements. One to six water-surface elevations were plotted on the profiles as reference points.

Staff Gauges

Irving and Burdick (1995) identified several important bottomlands within the Gunnison River study area. They placed staff gauges at some of these bottomlands to monitor water levels and estimate flows needed to inundate the floodplain habitats. They monitored temporary staff gauges in 1994, a year of moderate spring runoff. Even though some of the important habitats did not flood that year, stage-discharge relationships allowed them to predict when flooding might occur. When 1995 promised to be a high-runoff year, the temporary staff gauges were replaced at Confluence Park (RM 57.1; 0.8 mi upstream from the confluence of the Gunnison and Uncompahgre rivers) and Johnson Slough (RM 53.6) to validate the stage-discharge predictions (Irving and Burdick 1995). A third staff gauge was placed in an old oxbow of the Gunnison River in Escalante SWA (RM 52.3) that was part of Study Site 5. Water surface elevation at each of the staff gauges was recorded once or twice a week during runoff. Channel cross sections were surveyed at each site and bed-elevation data were related back to the staff gauge. Bed profiles were plotted and representative water elevations were placed on the graphs to visually assess when over-bank flooding occurred .

River Discharge

River discharge was measured by USGS gauges on the Gunnison River near Grand Junction (09149500; RM 14.6) and near Delta (09144250; RM 57.6; Figure

1). The Delta gauge was above the confluence with the Uncompahgre River and was therefore used in conjunction with the staff gauges at Confluence Park. All other study sites were downstream from the mouth of the Uncompahgre River and therefore the Grand Junction gauge was used for those sites. Although the gauge was about 40 mi downstream from the most upstream study sites, no other gauges were located within the study reach and it was the most representative gauge. No tributaries with measured flow enter the Gunnison River between the upper study site and the Grand Junction gauge. Several unmeasured tributaries enter the Gunnison between Escalante SWA and the gauge, but they are largely ephemeral and compose a very small fraction of the total flow of the Gunnison River. Although habitat mapping required 2 days, habitat area was related to mean-daily flow on the day video was taken. Differences in flow between the 2 days are a potential source of error, but comparison of flows between days for each mapping run indicated that these differences were small (mean, 5.7%; range, 1.1 – 8.3%). We could not correct for these differences.

Results

Surface area of habitat at the five study sites was mapped at seven flows; two in each year during 1993 – 1995 and one in 1996 (Figure 2; Table 2) . The highest flow when habitats were mapped was 15,800 cfs in 1993 and the lowest was 981 cfs in August 1994, which was the about the lowest flow that occurred in the Gunnison River during the 4 years of study. A full schedule for the Bureau's helicopter that required reservations more than a week in advance and rapidly changing flows during spring runoff in 1995 resulted in habitat mapping on 2 days with similar flows — 13,200 and 13,400 cfs. Total habitat area for the two flows differed by an average of 2.4% (range, 1.4 – 3.7%) at the five sites, so habitat area was averaged for graphical presentation.

Because the study sites are river reaches with different habitat components, habitat data were not combined for all sites as has been done in other studies describing shorter sections of river (e.g., Carter et al. 1985; Osmundson et al. 1995). Rather, descriptions of habitat changes are presented for each of the five study sites. The different responses to changes in discharge at the study sites could be used to predict habitat changes in other reaches of the Gunnison River with similar geomorphic configurations.

Site 1

This was the simplest study site examined (Figures 3, 4). It consisted of a long run with high banks that contained all flow at the highest discharges examined. The most abundant habitat at 981 cfs was slow run, with small amounts of pools, riffles,

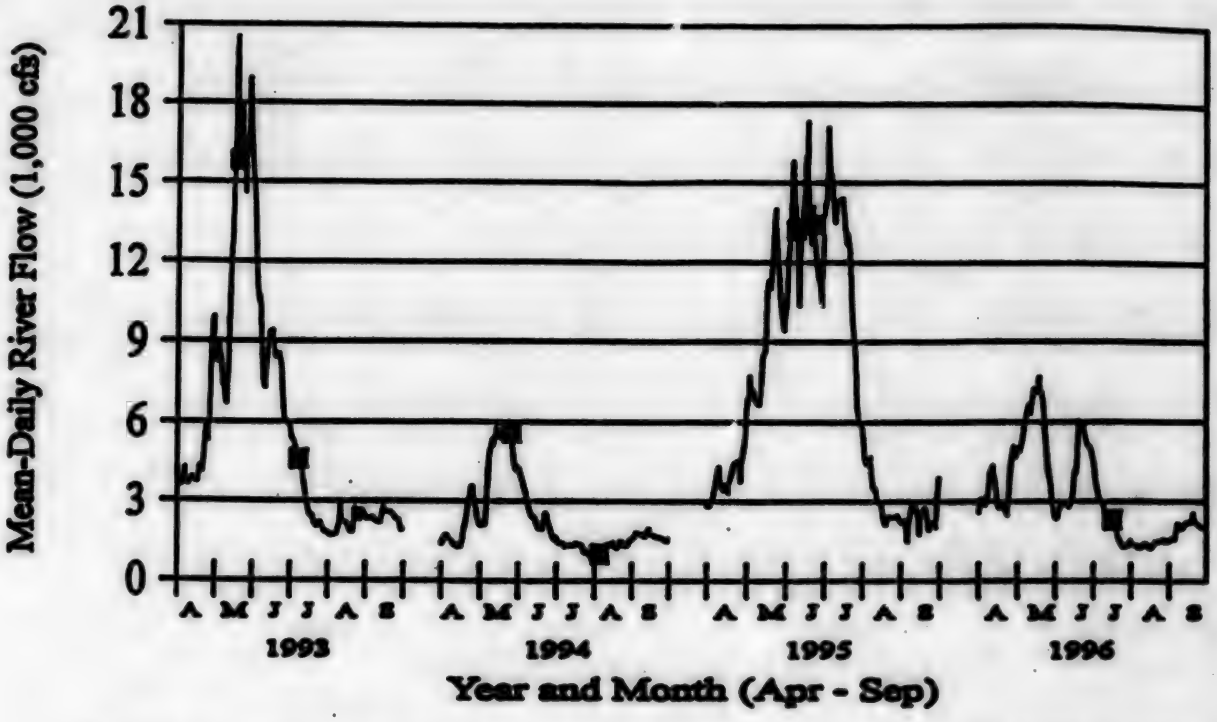

Figure 2. — Mean-daily river flow (cfs) of the Gunnison River at the USGS gauge near Grand Junction during April — September, 1993 – 1996. Habitat was mapped at flows marked with ■.

Table 2. — Mean-daily river flow (cfs) of the Gunnison River near Grand Junction on days when river habitat was mapped.

Mean Daily River Flow (cfs)	Date
15,800	May 20, 1993
13,400	June 23, 1995
13,200	June 9, 1995
5,560	May 25, 1994
4,500	July 8, 1993
2,300	July 16, 1996
981	August 5, 1994

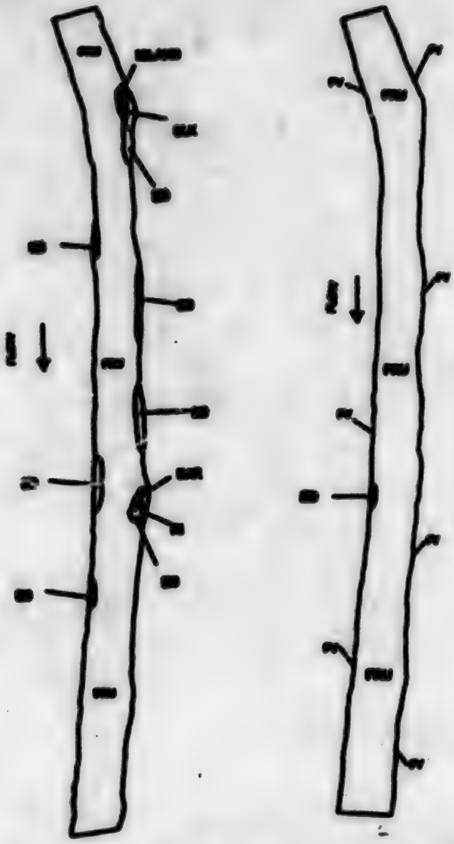

Figure 3. — Habitat maps of Study Site 1 at 2,300 cfs (July 16, 1996; left) and at 13,400 cfs (June 23, 1995; right). Mapping began at RM 31.8 and ended at RM 32.8. A key to abbreviations of habitat types is provided in Table A-1.

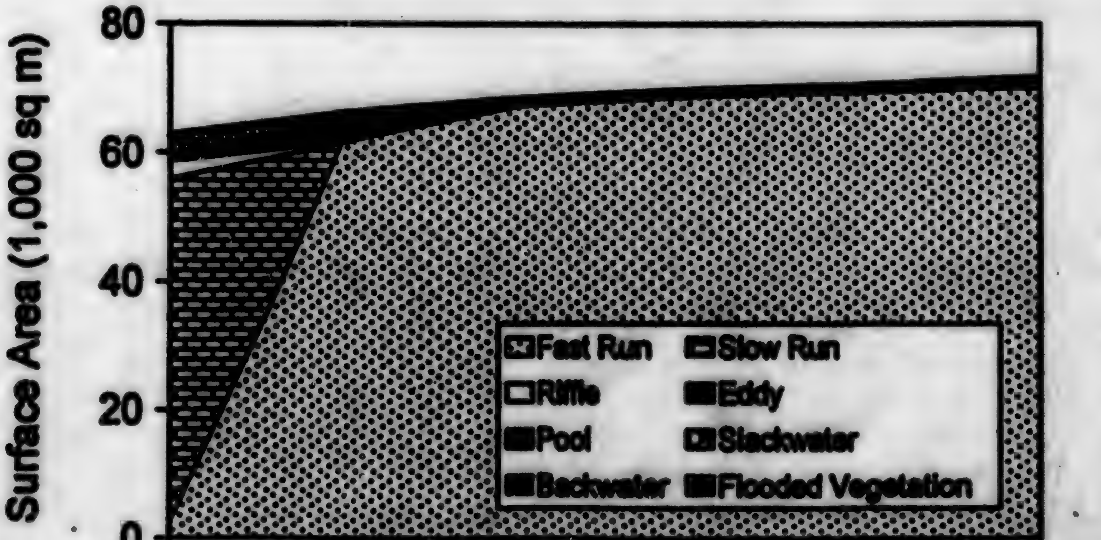

Figure 4. — Relationship of surface area of different habitat types to river discharge at Study Site 1, RM 31.8 – 32.4. Data are given in Table B-1.

and eddies. Fast run became the most abundant habitat at 2,300 cfs and remained so for all higher flows examined. Area of eddies increased slightly from 981 to 2,300 cfs, but they were almost eliminated at higher flows. Except for one small eddy, flooded vegetation (primarily *Tamarix* sp. and *Salix* sp.) along the shoreline of the river was the only habitat other than fast runs available at flows greater than 2,300 cfs. Flooded vegetation was available at all but the lowest discharge. Because of tall banks that contained all of the river's flow at the measured discharges, total surface area of the river increased minimally as discharge increased.

Two cross sections were surveyed at this site and they showed relatively little change over the course of the study (Figure 5). The confined, U-shaped channel explains the very simple habitat types available, since the straight banks essentially created a high-velocity ditch at higher flows. Except for a small amount of deposition at RM 31.2 after fall 1994, very little change in the river bed occurred over the course of the study.

Site 2

This site was a pool-eddy complex that had a variety of habitats available at flows less than 4,500 cfs (Figures 6, 7). Pool, eddy, and slow run habitats were about equal in area at 981 cfs. Increasing water velocities caused area of fast run to increase as discharge increased. Surface area of fast runs increased with discharge to about 4,500 cfs when the increase leveled off. Pool habitat disappeared at 4,500 cfs, but area of eddies increased at flows above 4,500 cfs. The eddies were caused by rocks and irregularities along the western shoreline which interrupted the uniform downstream flow. Rocks and a constriction in the channel formed a hydraulic rapid at about 4,500 cfs. A large eddy was also created at the downstream end of the rapid. The rapid was an important habitat component between flows of 4,500 to 13,300 cfs, but it became a fast run at 15,800 cfs. Flooded vegetation became a minor component at 13,000 to 15,800 cfs as the water rose high enough to flood tamarisk along the eastern shoreline. Slack water also became important at 15,800 cfs as water rose high enough to cover a gentle slope covered with terrestrial vegetation at the downstream end of the study site.

Two cross sections were surveyed at this site — below (RM 33.7; Figure 8) and above (RM 34.0; Figure 9) the constriction that formed the rapid at high flows. Both of these sites were pools or slow runs at low flows and fast runs with eddies at high flows. A dike on the northeast side of the river protected an orchard and confined the river at high flows. The channel at the upper transect was also confined by cliffs on the southwest side of the river. A tapered bank on the west shoreline allowed some out-of-bank flooding at higher flows. Although some scouring and deposition occurred over the course of the study, no major changes in channel configuration occurred at either transect. The upper transect experienced some scouring along

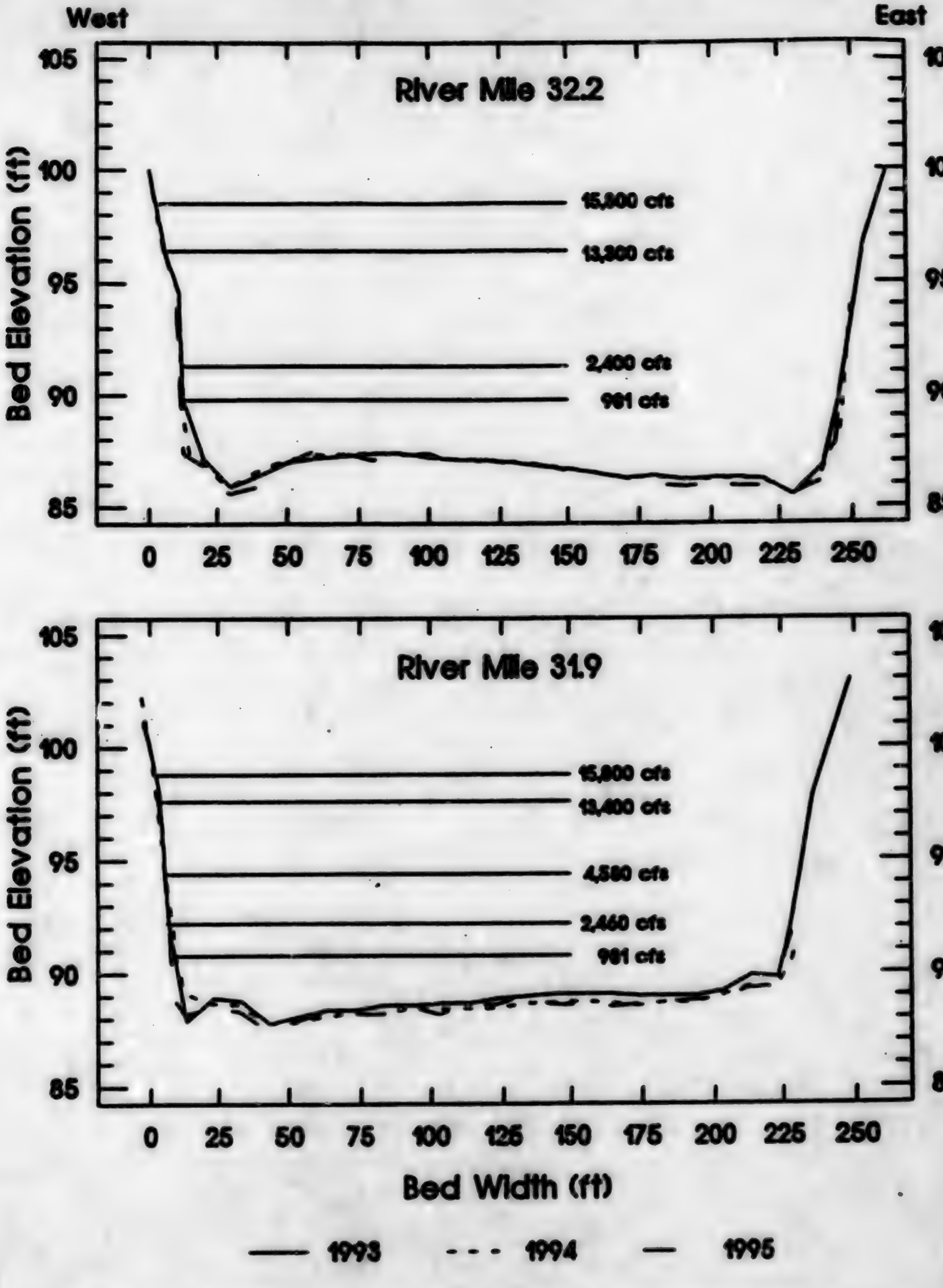

Figure 5. — Two cross sections of the Gunnison River at Study Site 1.

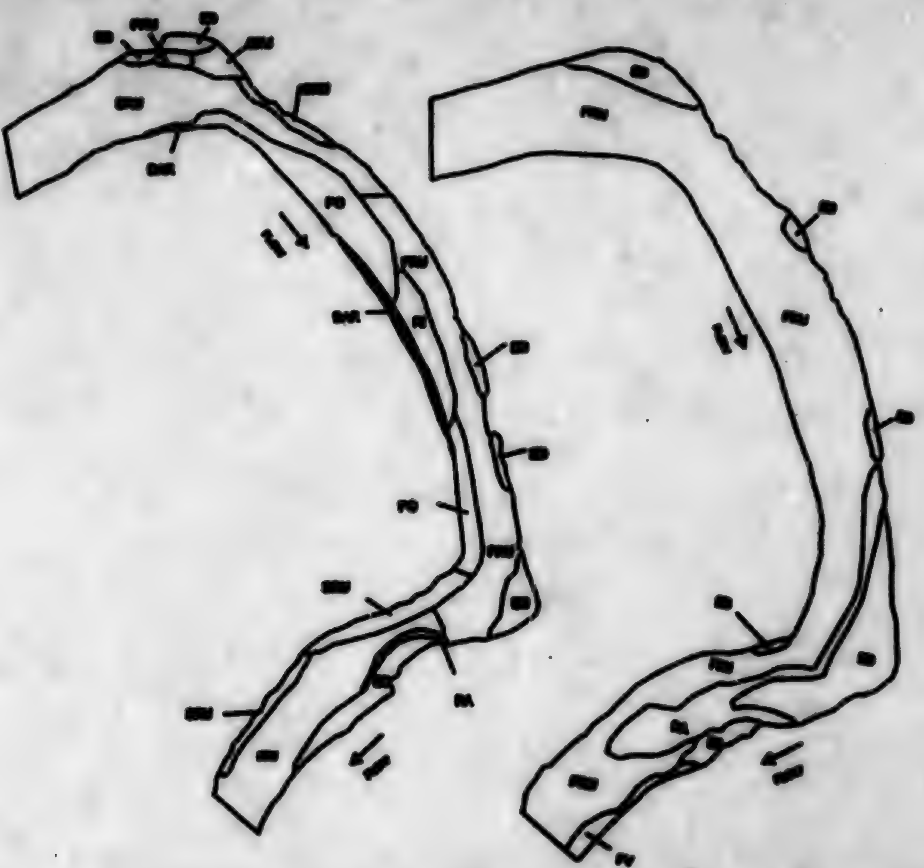

Figure 6. — Habitat maps of Study Site 2 at 2,300 cfs (July 16, 1996; left) and at 13,400 cfs (June 23, 1995; right). Mapping began at RM 33.6 and ended at RM 34.1. A key to abbreviations of habitat types is provided in Table A-1.

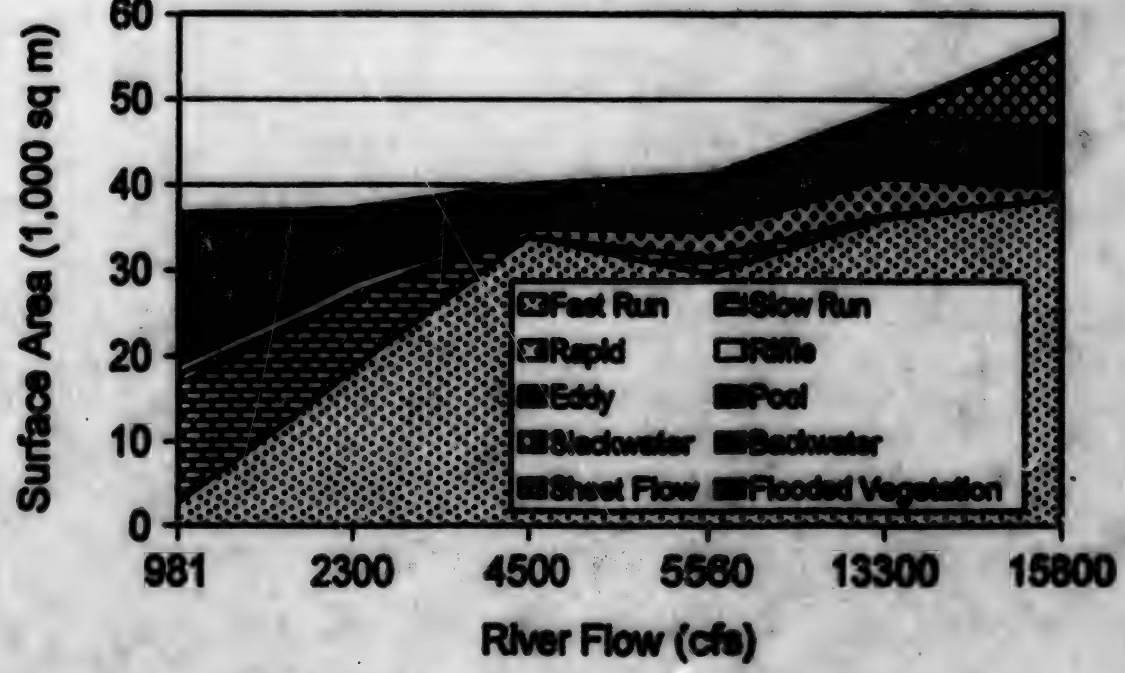

Figure 7. — Relationship of surface area of different habitat types to river discharge at Study Site 2, RM 33.6 – 34.1. Data are given in Table B-2.

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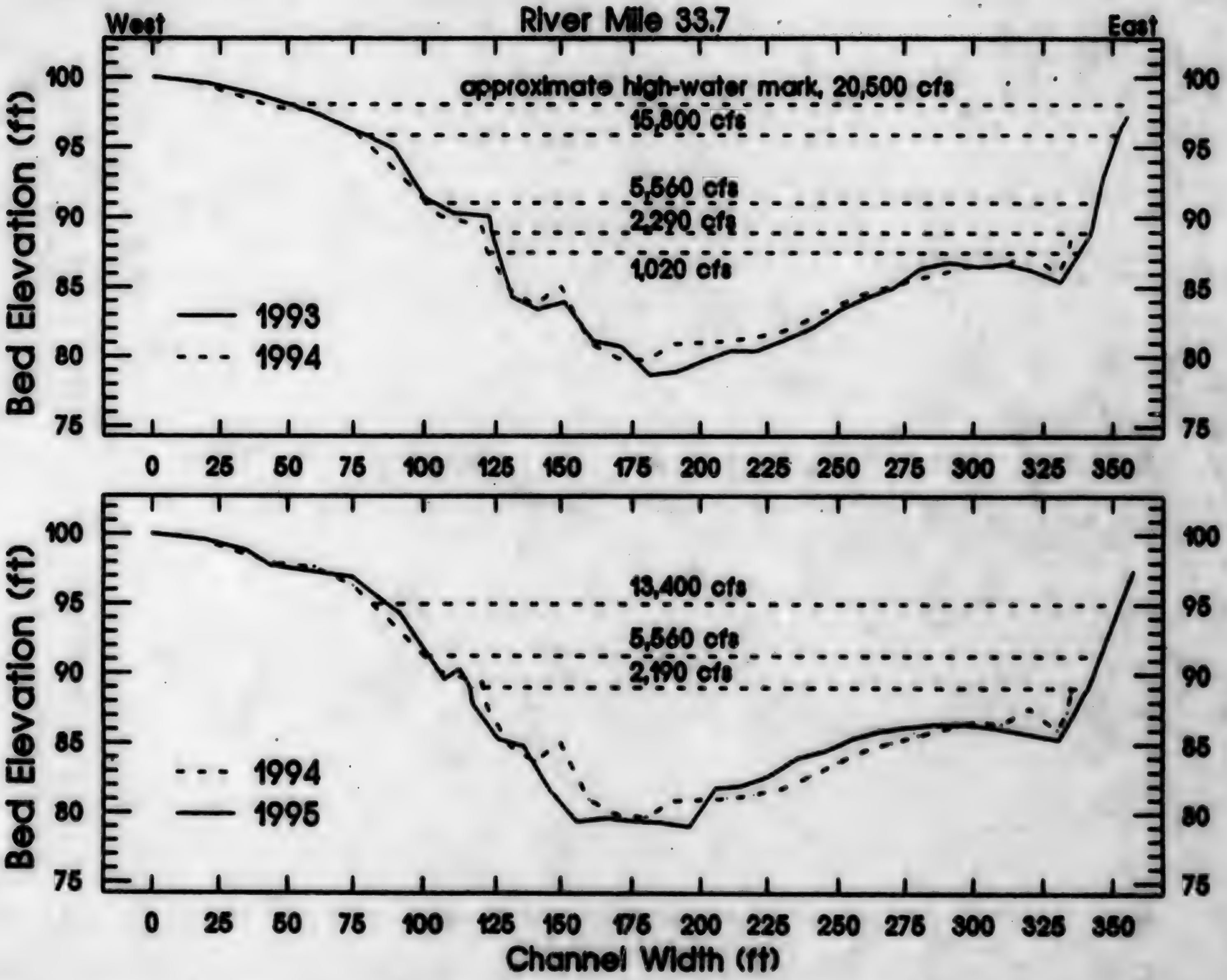

Figure 8. — Cross section of the Gunnison River at RM 33.7, Study Site 2.

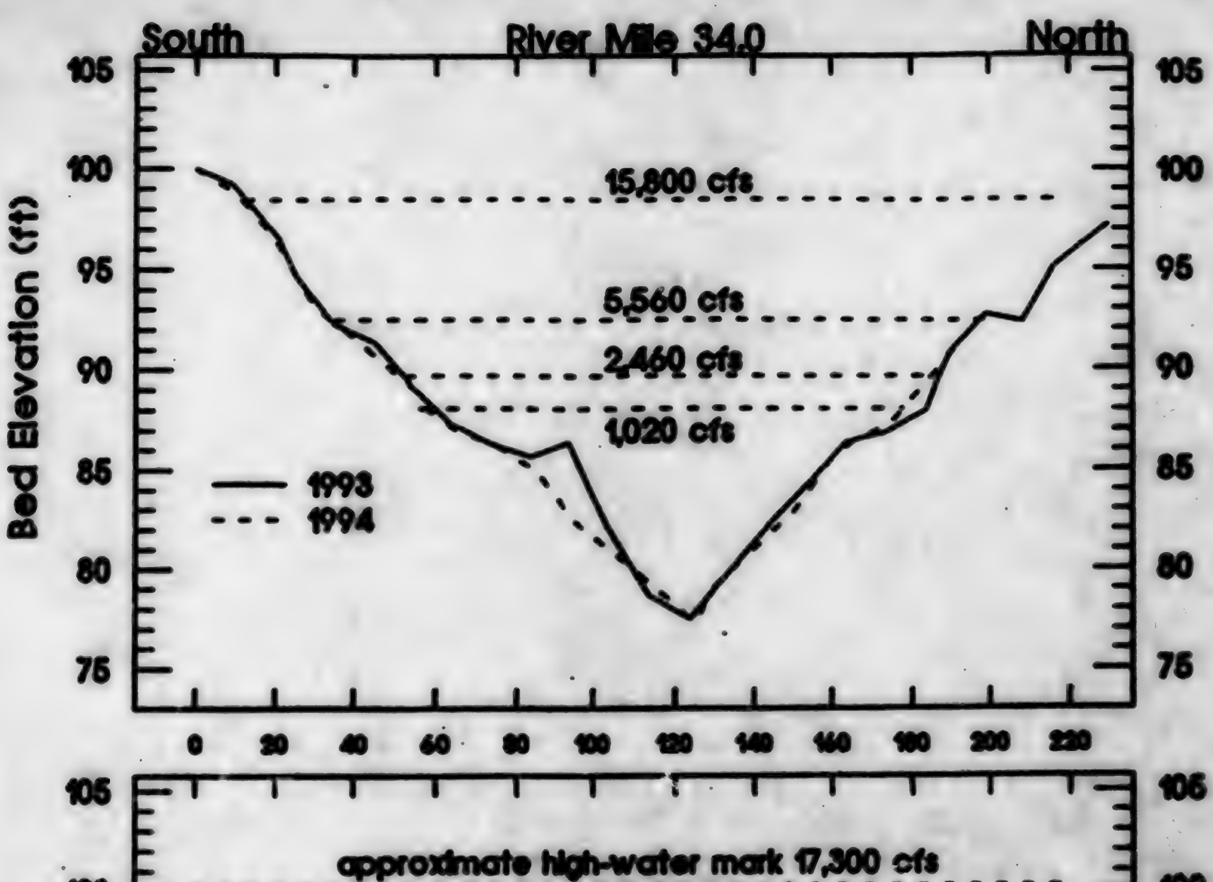

Figure 9. — Cross section of the Gunnison River at RM 34.0, Study Site 2.

the south shore in 1994 and along the north bank in 1995. The lower transect experienced scouring along the west bank and deposition in the middle of the river bed in both 1994 and 1995.

Site 3

Site 3 consisted of a large vegetated island with the main river channel on the northeast side and a complex of small islands, gravel bars, and side channels on the southwest side. Surface area of slow runs was greatest at 981 cfs and area of pools was greatest at 2,300 cfs (Figures 10, 11). Riffles were important components of available habitats at flows between 2,300 cfs and 5,560 cfs as rising water covered parts of the bars. Because the island and bars produced an irregular and complex shoreline, surface area of eddies was fairly constant at all flows examined. Total surface area increased gradually up to 5,560 cfs, but increased substantially between 5,560 and 13,200 cfs since most of the gravel bars were covered at the higher flow. This was the largest gap between measured flows in the study. Sheet flow began at 13,200 cfs and increased slightly at 15,800 cfs as flowing water covered substantial parts of the main island. Although not measured, mud, depressed vegetation, and other signs of flooding indicated that most of the large island had been covered at the peak of runoff in 1993 (20,000 cfs) and 1995 (17,300 cfs).

Three transects were surveyed at Site 3. Two primary transects were established in 1993 (Figures 12, 13) and a third was added in a pool at the upper end of the study site in the low-water year of 1994 (Figure 14). The lower transect crossed the entire river from southwest to northeast. It crossed a side channel with several gravel bars exposed at low water levels, the lower end of a vegetated island (covered at higher flows), and the main channel to terminate on the northeast shoreline. The middle transect crossed the side channel and gravel bar complex and terminated in the middle of the vegetated island. The upper transect crossed the main channel above the island. These transects showed no major changes over the course of the study, although quite a bit of scouring and deposition occurred among the gravel bars in the side channel. The largest changes occurred between 1994 and 1995 when 1-2 ft of gravel were scoured from several places along both transects and 4 ft of gravel were deposited at one spot at RM 34.7. Visual observations of the side channel suggest more scour and fill than indicated in the two transects. The side channel eroded and widened during runoff in 1996. The upper transect crossed an area that was a pool at low water. Because this transect was not surveyed in 1993, we can not determine whether material was deposited in the pool during the low-water year of 1994. However, about 2 ft of material were scoured from the bottom and side of the pool in the high water year of 1995.

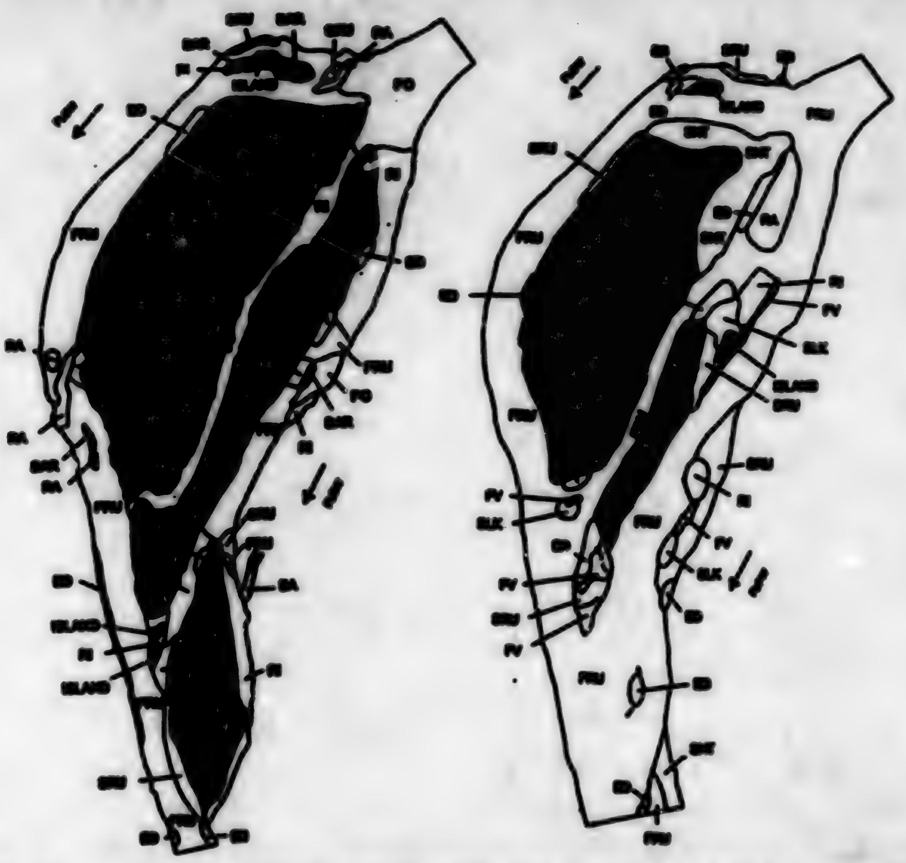

Figure 10. — Habitat maps of Study Site 3 at 2,300 cfs (July 16, 1996; left) and at 13,400 cfs (June 23, 1995; right). Mapping began at RM 34.3 and ended at RM 34.9. A key to abbreviations of habitat types is provided in Table A-1.

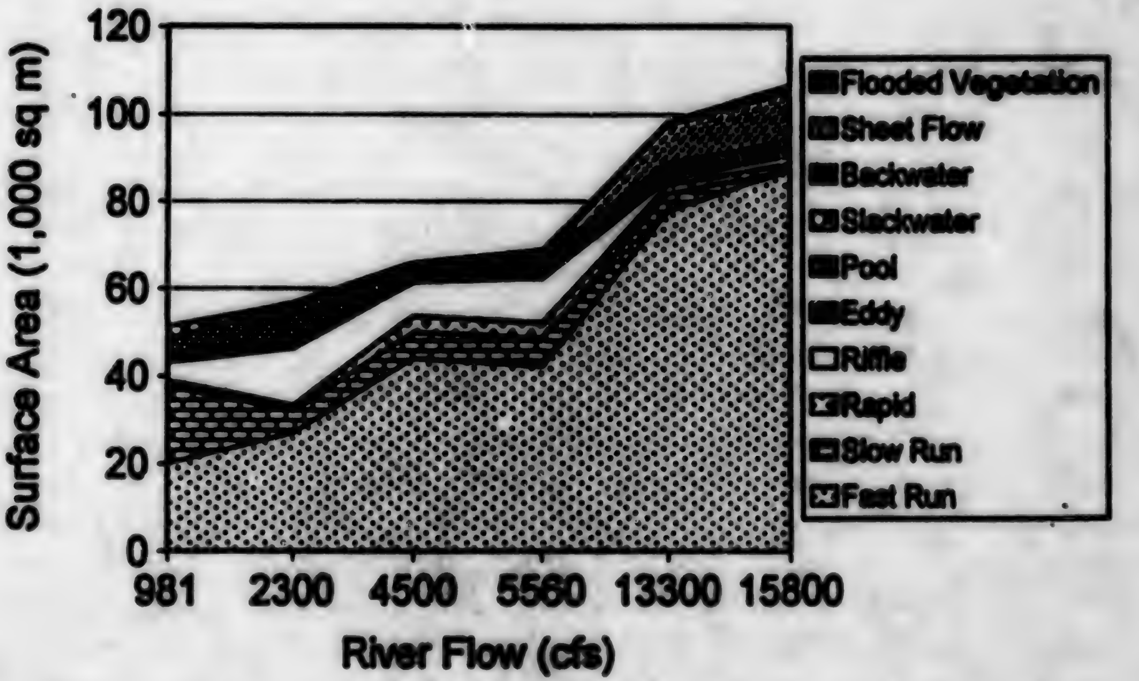

Figure 11. — Relationship of surface area of different habitat types to river discharge at Study Site 3, RM 34.3 – 34.9. Data are given in Table B-3.

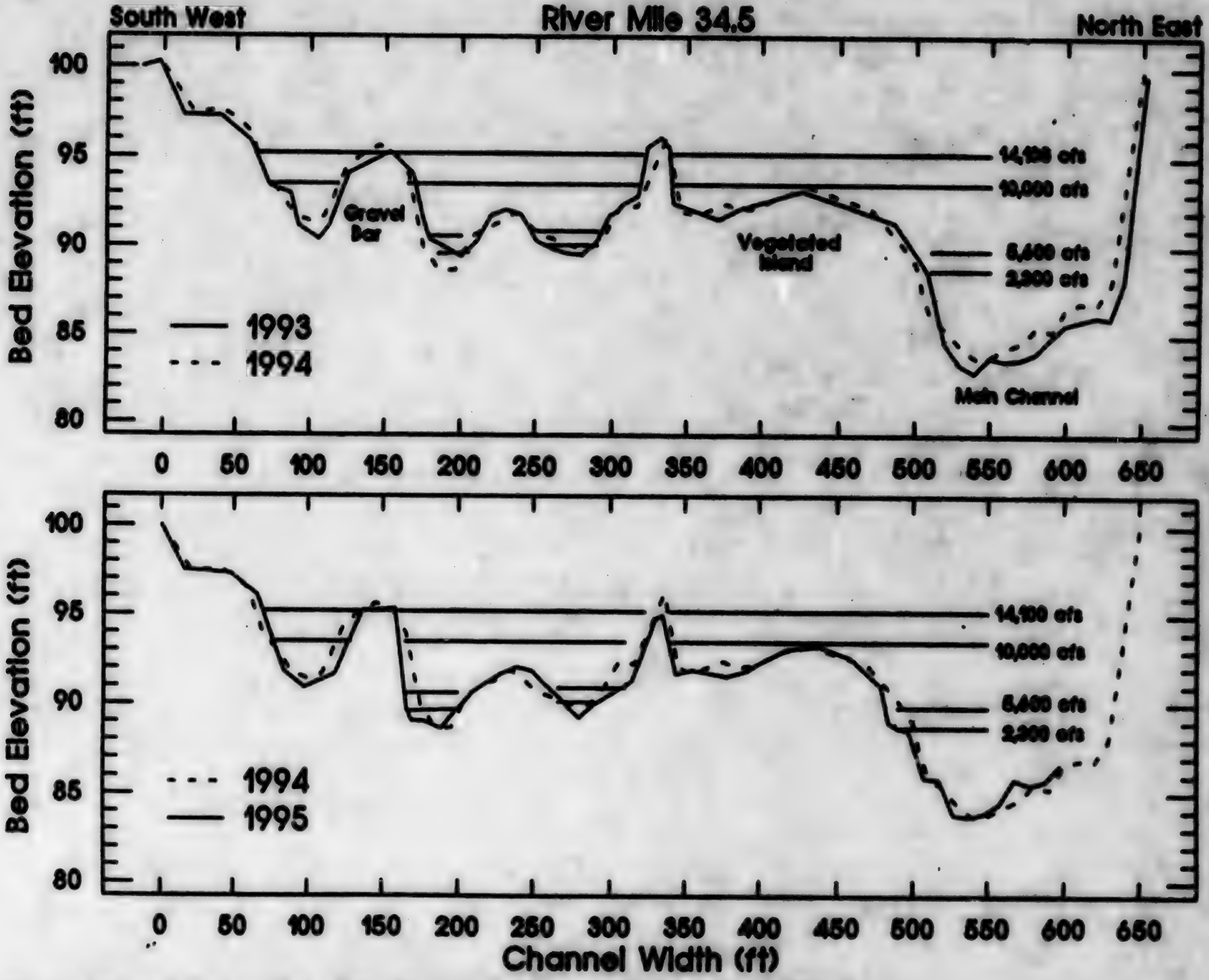

Figure 12. — Cross section of the Gunnison River at RM 34.5, Study Site 3.

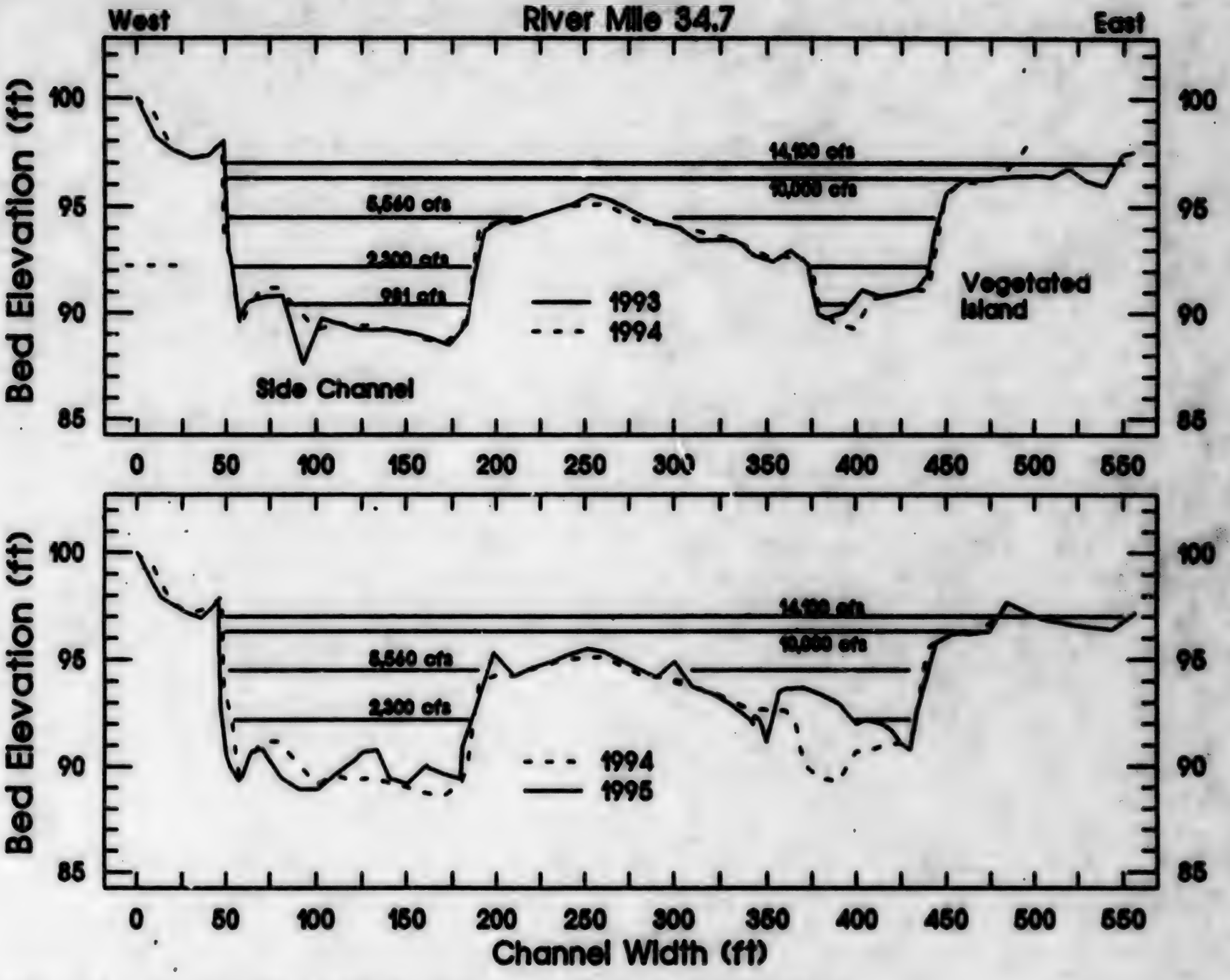

Figure 13. — Cross section of the Gunnison River at RM 34.7, Study Site 3.

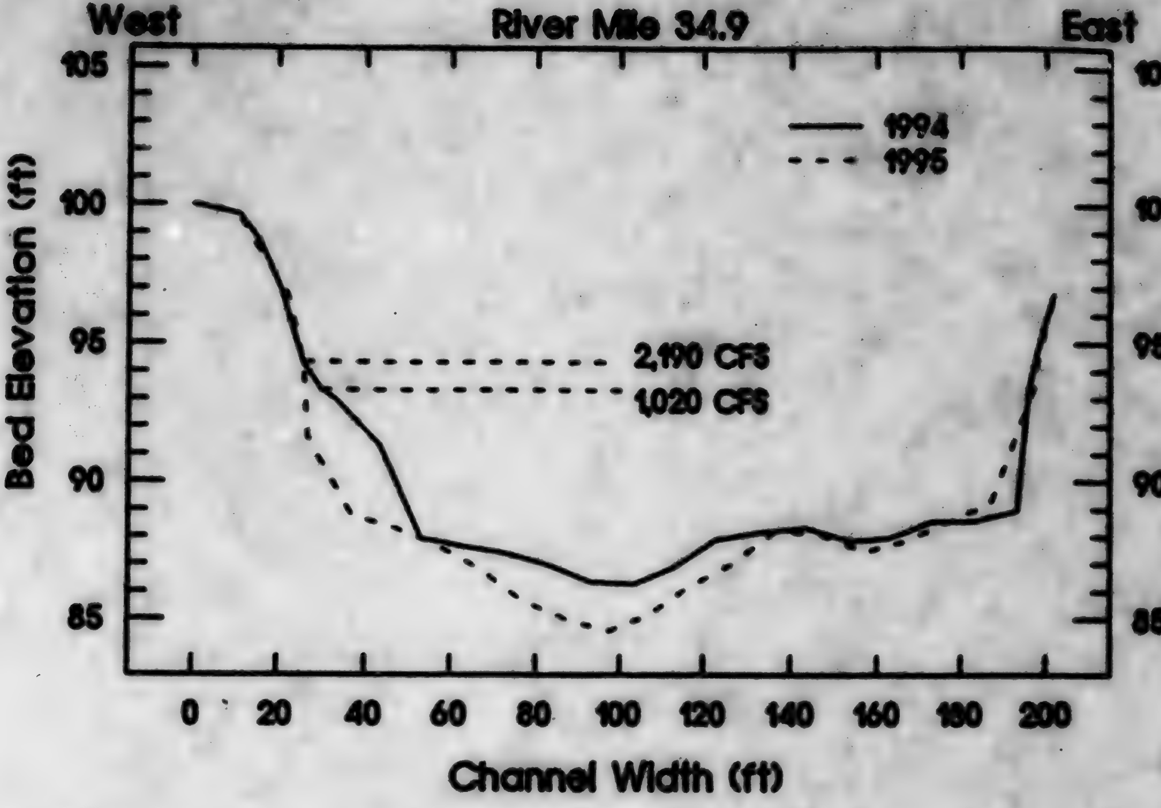

Figure 14. — Cross section of the Gunnison River at RM 34.9, Study Site 3.

Site 4

Site 4 was composed of a channel with moderately steep sides with two gravel-bar islands which split the flow into two roughly equal side channels. A mixture of habitats including fast and slow runs, riffles, eddies, and pools was available at 981 and 2,300 cfs (Figures 15, 16). Fast run rapidly increased in surface area up to 5,560 cfs. Although surface area of fast run continued to increase, the rate of increase declined between 5,560 and 13,200 and then declined further between 13,400 and 15,800. The most abrupt increase in total habitat area occurred between 4,500 and 5,560 cfs when most of the two islands were covered with flowing water. The steep banks and cliffs along the river then constrained the water as discharge increased. Riffles were common as water was rising, but disappeared after the gravel bars became inundated. Surface area of eddies was relatively constant, ranging between 1,600 and 3,000 m^2 at all flows studied. Flooded vegetation was available at 4,500 cfs, but area increased substantially at 5,560 cfs and higher. Slack water was found in shallow areas around the islands at the two low flows. Sheet flow appeared at 15,800 cfs as water reached gradual slopes outside the main channel of the river.

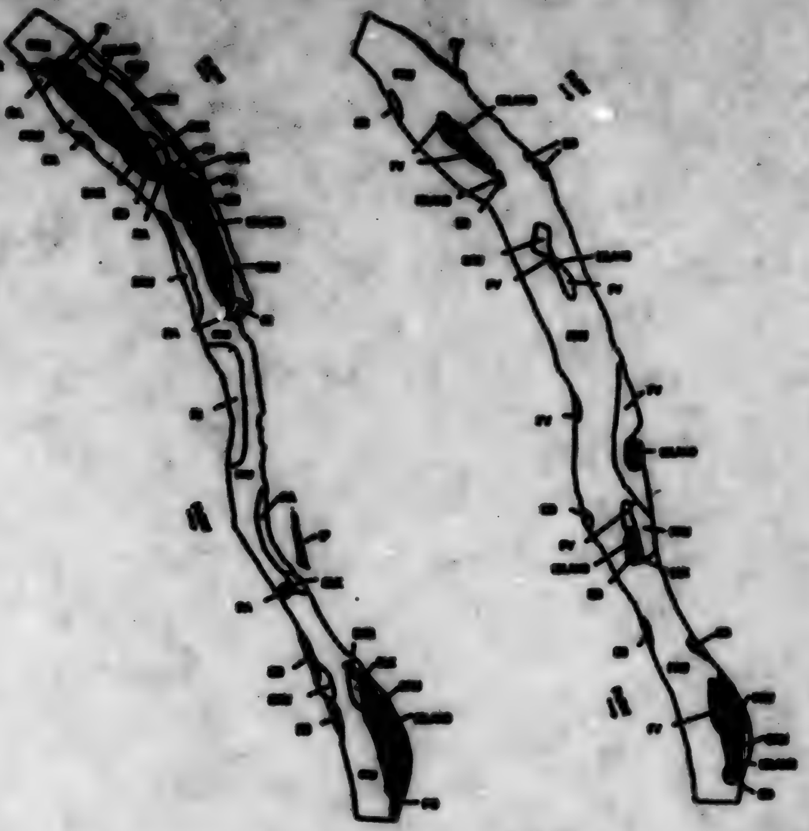

Figure 15. — Habitat maps of Study Site 4 at 2,300 cfs (July 16, 1996; left) and at 13,400 cfs (June 23, 1995; right). Mapping began at RM 37.4 and ended at RM 38.3 A key to abbreviations of habitat types is provided in Table A-1.

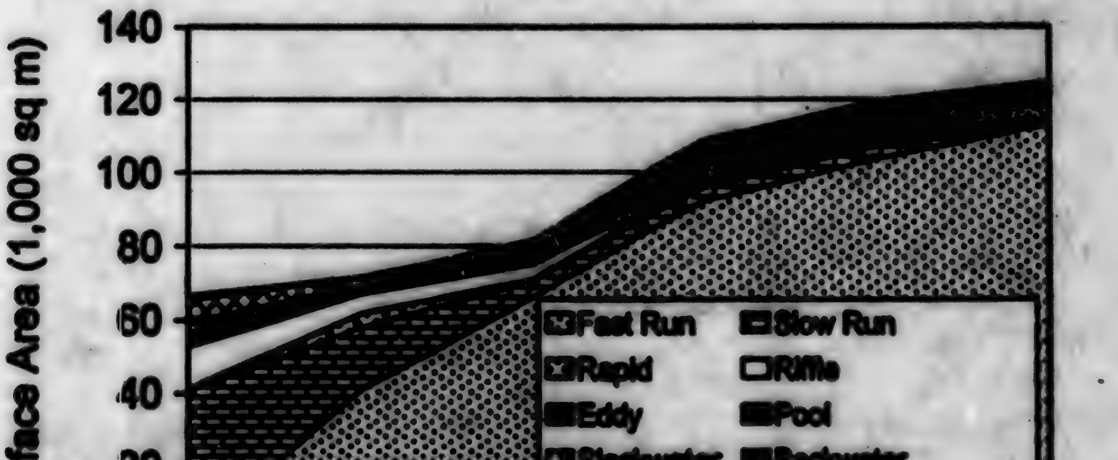

Figure 16 — Relationship of surface area of different habitat types to river discharge at Study Site 4, RM 37.4 – 38.3. Data are given in Table B-4.

No transects were surveyed here because this site was included in the cooperative study by Reclamation and USGS. Two of the 18 transects surveyed by Milhous (in press) were plotted to assess channel changes at this study site (Figure 17). Major changes occurred at both transects. About 30 ft of bank was eroded from the steep eastern shoreline of the transect at RM 37.6 during runoff in 1995. In addition, about 1 ft of material was deposited on the gravel bar in the middle of the channel. Some erosion also occurred along the lower portion of the western shoreline. Most change in bed profile occurred between 1993 and 1995; it changed very little between 1995 and 1996. The eastern shoreline of the lower transect (RM 37.5) was a steep rock face which prevented any erosion along that part of the river bank. However, quite a bit of scouring occurred along the eastern edge of the gravel bar in the middle of the channel. In addition, about 4 ft of material was deposited on the western side of the same gravel bar. Unlike the other transect where most change occurred between 1993 and 1995, scouring and deposition at the lower transect occurred about equally between 1993 – 1995 and between 1995 – 1996.

Site 5

Site 5 was a wide floodplain consisting of a large island, two main channels at high water and extensive floodable low-lying areas. This site had a high diversity of habitats at all flows examined (Figures 18, 19). Fast and slow runs were the most abundant habitats at 981 cfs, but a variety of backwaters, riffles, and eddies were also present. Area of fast runs, backwaters, riffles, and eddies increased as discharge increased to 2,300 cfs. Increase in total surface area leveled out between 2,300 and 5,560 cfs, with area of fast runs actually decreasing between 4,500 and 5,560 cfs. Slow runs increased during that period. Total surface area increased more than 100% when discharge increased from 5,560 to 13,200 cfs and then increased about the same amount again when discharge increased to 15,800 cfs. The large increase in total surface area from 5,560 to 13,200 cfs resulted primarily from inundation of three large habitat features. At some level above 5,560 cfs a large side channel on the south side of the river filled and contributed quite a bit more run habitat. Water levels rose enough that water flowed over much of the main island (sheet flow and slack water) and inundated a large bottomland on the north side of the river. This bottomland contributed both flooded vegetation and low-velocity, open-water habitat (>1 ft deep with relatively little emergent vegetation). Parts of these habitats had strong currents moving through them, but large sections had relatively quiet water. At 15,800 cfs most of the island was covered with fast moving water, and the river left its banks on the west side of Escalante SWA and covered a bench that usually stays above water level. Both sheet flow and slack water were formed on the island and on the bench.

Three cross-channel transects were surveyed at Site 5. The upper transect (RM 52.2; Figure 20) was across the river channel in a location with stable bottom and

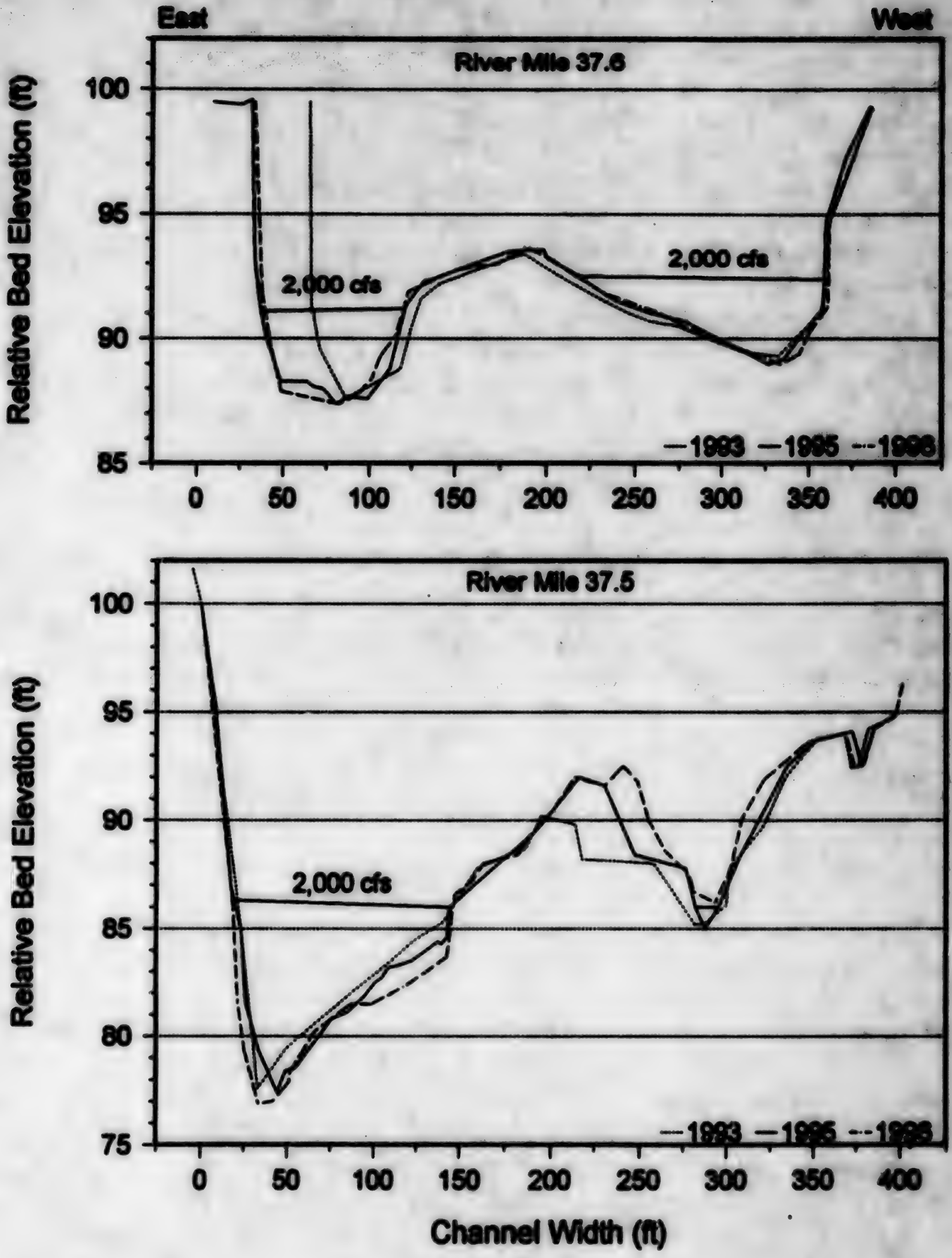

Figure 17. — Two cross sections of the Gunnison River at Study Site 4.

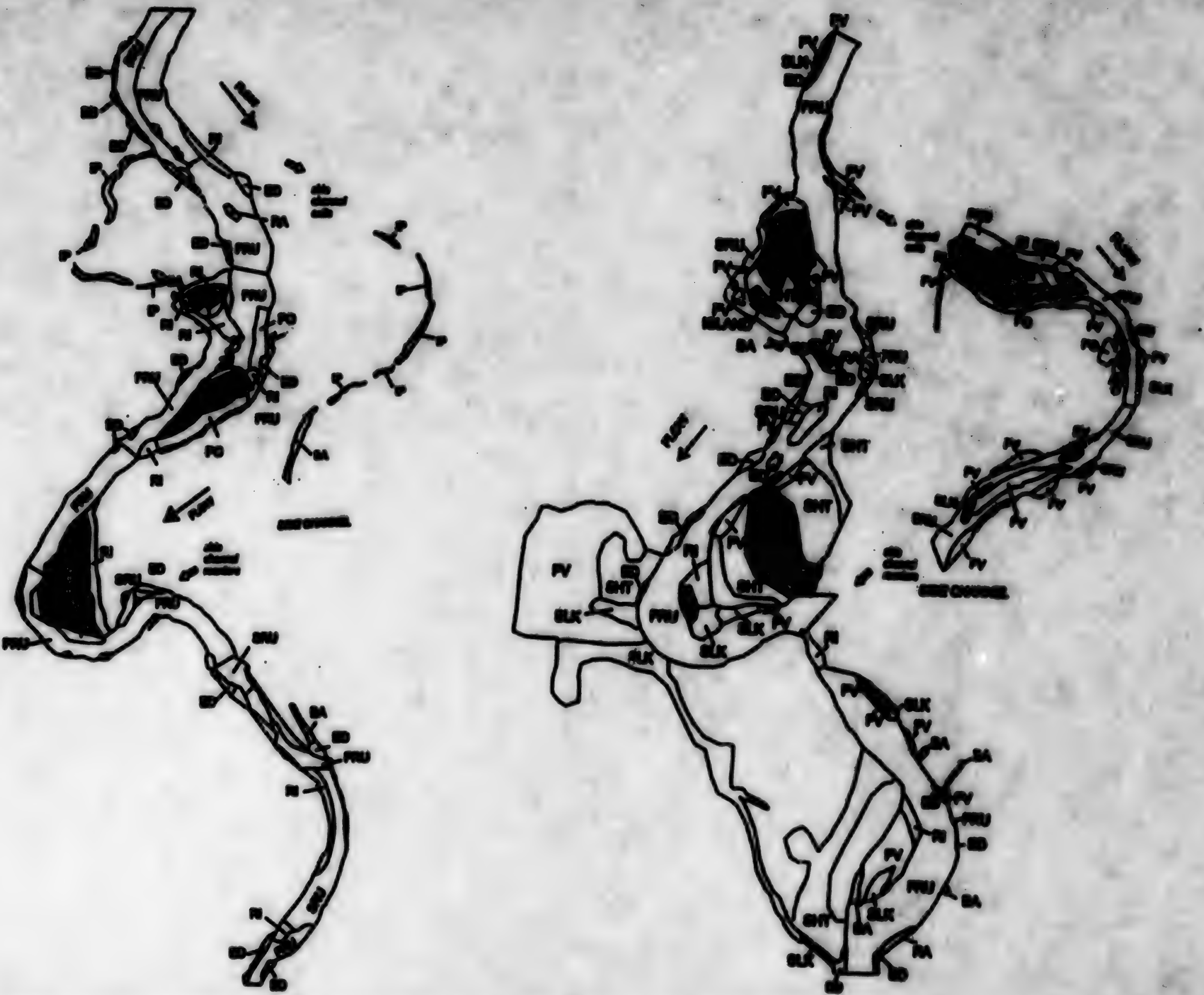

Figure 18. — Habitat maps of Study Site 5 at 2,300 cfs (July 16, 1998; left) and at 13,400 cfs (June 23, 1998; right). Mapping began at RM 50.7 and ended at RM 52.3. A key to abbreviations of habitat types is provided in Table A-1.

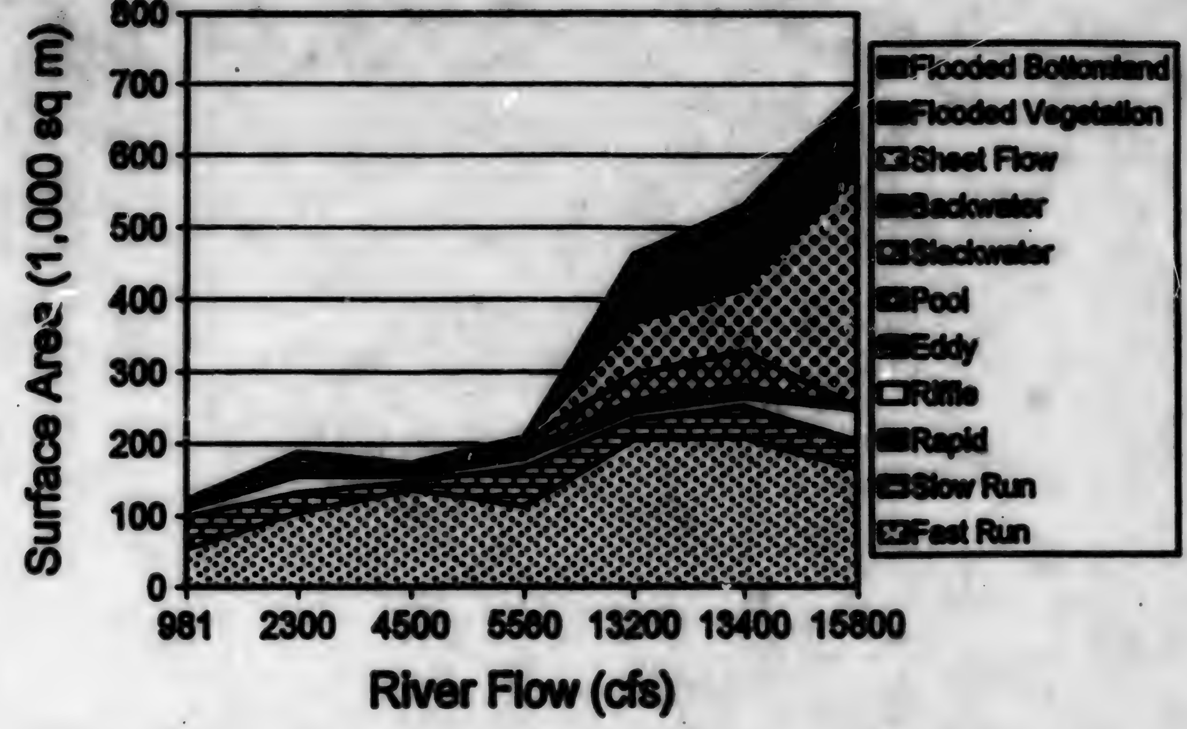

Figure 19. — Relationship of surface area of different habitat types to river discharge at Study Site 5, RM 50.7 – 52.3. Data are given in Table B-5.

shorelines. No appreciable change occurred at this site. A bar on the north side of the river that formed a shallow backwater at low flow did exhibit small amounts (<0.5 ft) of scouring and deposition over the survey period, with most of the deposition occurring during the high water year of 1995. The middle transect (RM 51.7; Figure 21) ran from the large vegetated island in the middle of Escalante SWA, across the main channel, over a small vegetated island/gravel bar, and across a side channel to the north shoreline. This section of the Gunnison River experienced quite a bit of change over the course of the study, only part of which was documented by the transect. The bed profile shows some deposition along the south side of the main channel and some scouring (~1 ft) along both sides of the island in 1994. However, about 20 ft of the upstream end of the island was removed by runoff in 1994, a relatively low runoff year. Spring runoff in 1995 removed another 80 ft of the gravel bar downstream to just above the transect. It also eroded about one-half the width of the island (~50 ft) along the transect (Figure 21). All of the island on and upstream of the transect was removed by spring runoff in 1996. Most of the material eroded from the island over the 4-yr study was deposited 0.1 – 0.2 mi downstream in the middle of the channel creating another gravel bar complex. The lowermost transect (RM 51.1; Figure 22) ran from a steep bank along the east side of the river to a gradually sloping gravel bar that was covered with permanent vegetation at its upper elevations. The gravel bar did not change appreciably over the course of the study, but about 16 ft of the eastern shoreline was eroded during spring runoff in 1995.

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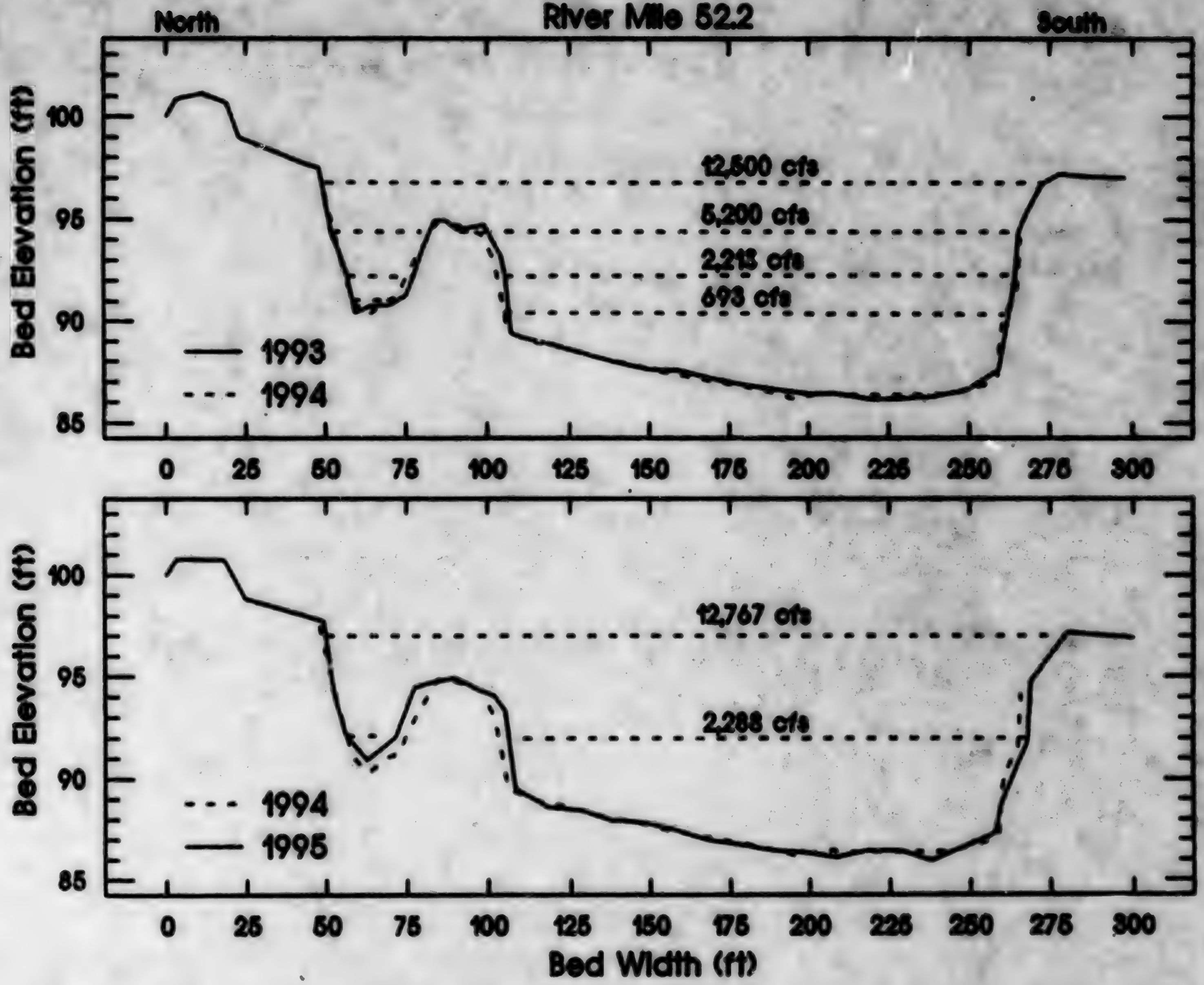

Figure 20. — Cross section of the Gunnison River at RM 52.2, Study Site 5.

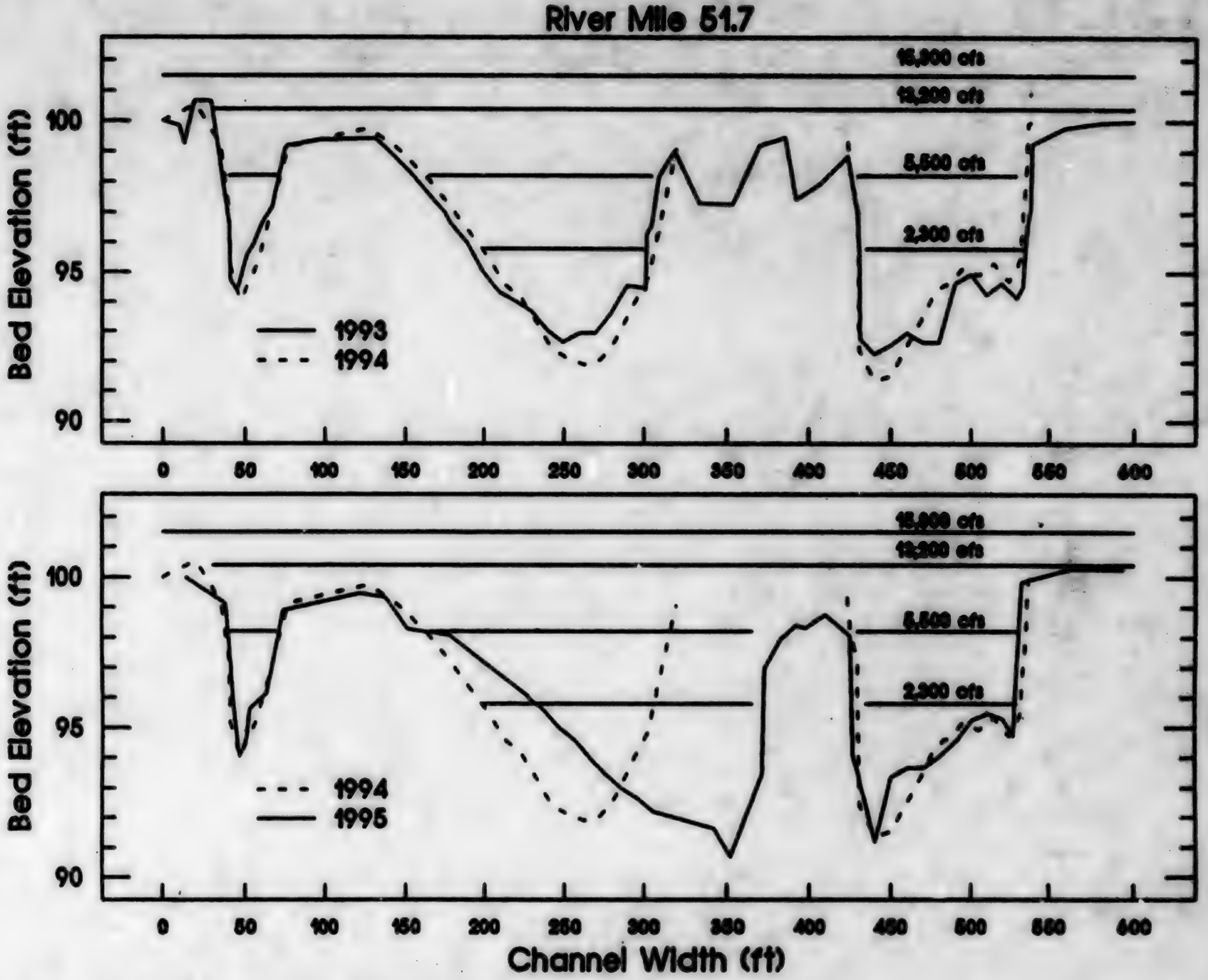

Figure 21. — Cross section of the Gunnison River at RM 51.7, Study Site 5.

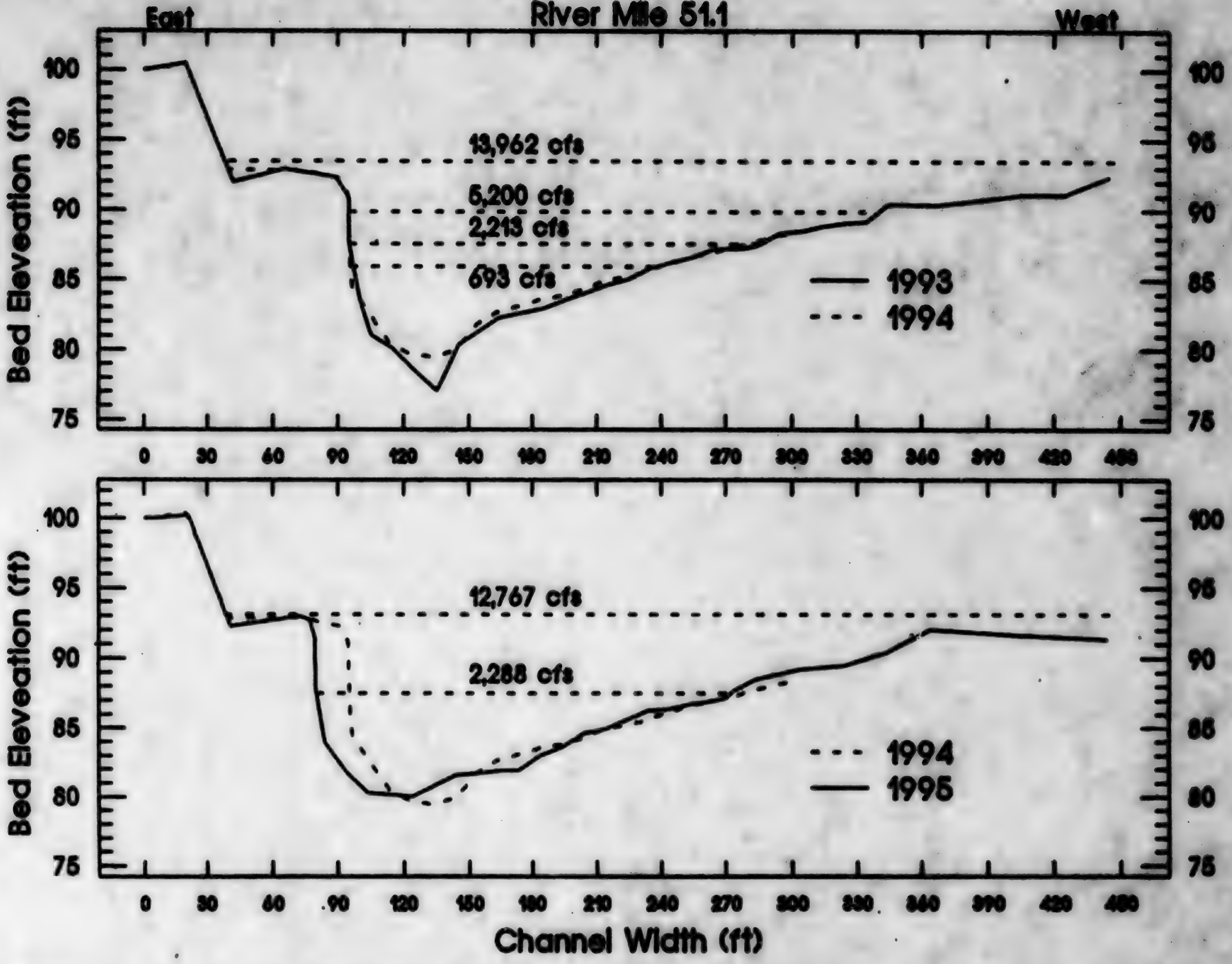

Figure 22. — Cross section of the Gunnison River at RM 51.1, Study Site 5.

Staff Gauges

Confluence Park — Two staff gauges were placed on the north bank of the Gunnison River just upstream from its confluence with the Uncompahgre River. The most upstream gauge was located in the same position used by Irving and Burdick (1995; RM 57.1) and a second was placed about 0.2 mi downstream (RM 56.9), at the lower end of the floodable area (Figure 23). The area did not flood during Irving and Burdick's evaluation, but they predicted flooding at the upper end of the area at flows of 8,000 – 9,000 cfs. Results in 1995, indicated that water entered the floodable area upstream of the transect at about 9,000 cfs, validating their prediction. However, substantial flooding did not occur until about 10,000 cfs. The downstream portion flooded at lower flows, with limited flooding occurring at 5,000 – 6,000 cfs. This was the only study site that used the USGS gauge at Delta, CO to measure river flow.

Johnson Slough — One staff gauge was placed on a dike along the north side of the Gunnison River at RM 53.6, near the location used by Irving and Burdick (1995). The staff gauge was immediately downstream from the entrance to a marsh that was the remains of an old river oxbow. Irving and Burdick predicted that flooding would occur at about 10,000 cfs. Based on the cross-section data in 1995, flows would have needed to exceed about 14,000 cfs to top the dike at the transect line (Figure 24). However, the entrance to the oxbow was just upstream from the transect and was connected to the river at 5,000 – 6,000 cfs; quite a bit of flooding occurred behind the dike at flows exceeding 7,000 cfs. Also quite a bit of flooded shoreline was located downstream from the dike at similar flows.

Escalante SWA — The final staff gauge was located in an old oxbow of the Gunnison River in the middle of habitat-mapping Site 5. The oxbow was a large terrace that formed a large flooded habitat at high water (Figure 25). About one-half of the area was covered with vegetation (primarily *tamarisk*) and the other half was an open area of hard-packed sand and silt. Water began to enter the oxbow at about 6,000 cfs. However, the staff gauge was across the main channel from a large island that also flooded at high water. The water also spread out over the island at higher flows so large increases in river flow resulted in relatively small increases in water depth in the oxbow. However, flows exceeding 13,000 cfs resulted in 1 – 2 ft of water in many parts of the flooded oxbow. High river flows produced strong currents flowing through parts of the oxbow, but large areas of quiet water were also available.

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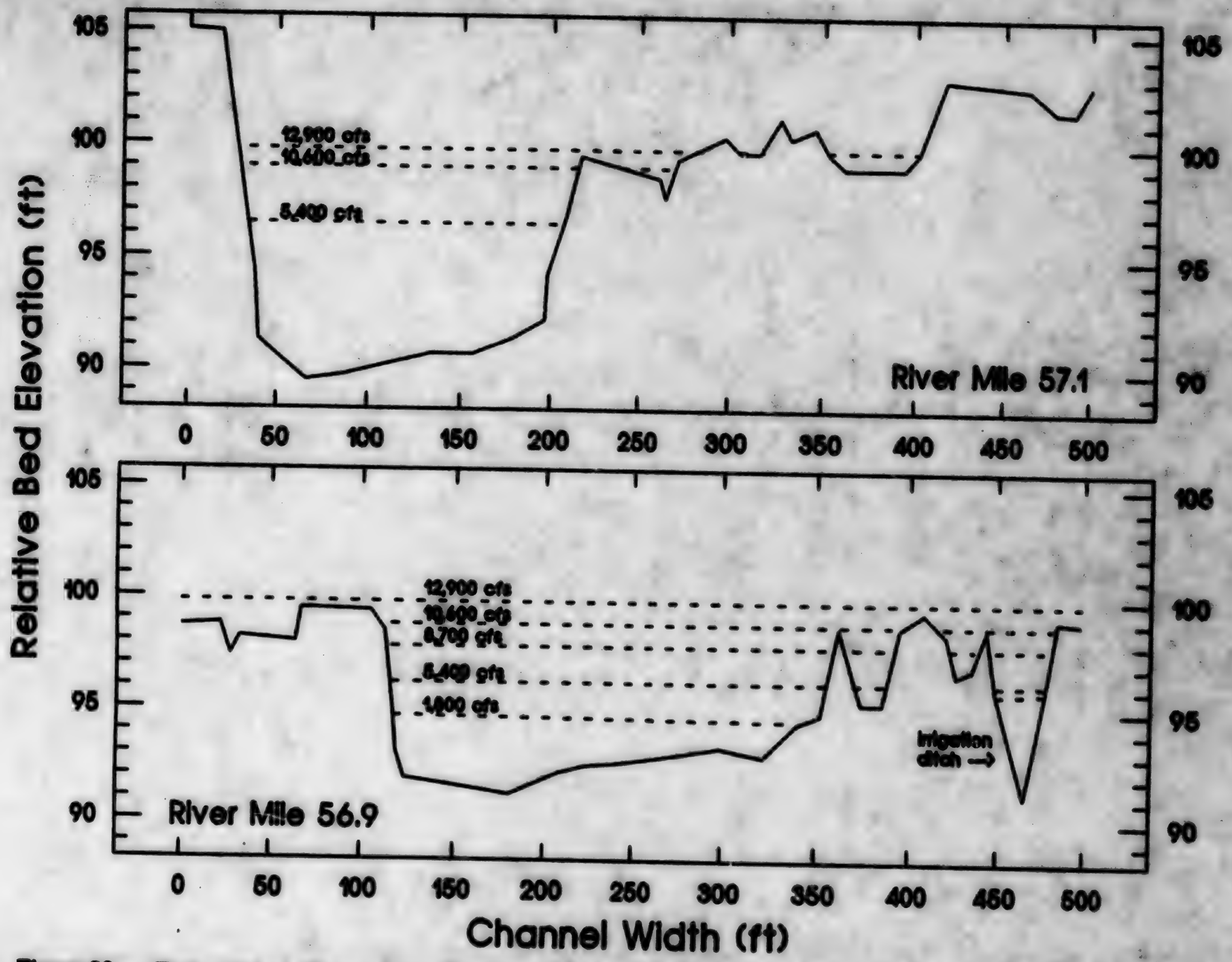

Figure 23. — Two cross sections of the Gunnison River near Confluence Park, RM 57.1 and 56.9.

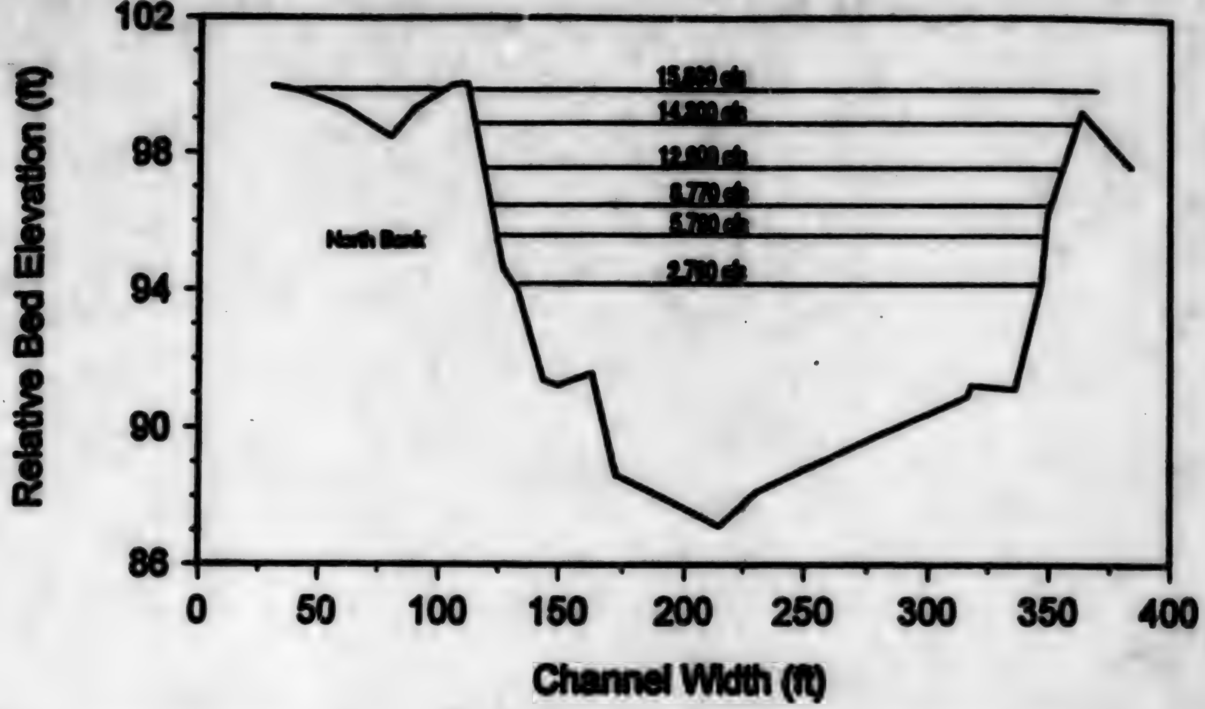

Figure 24. — Cross section of the Gunnison River at Johnson Slough, RM 53.6.

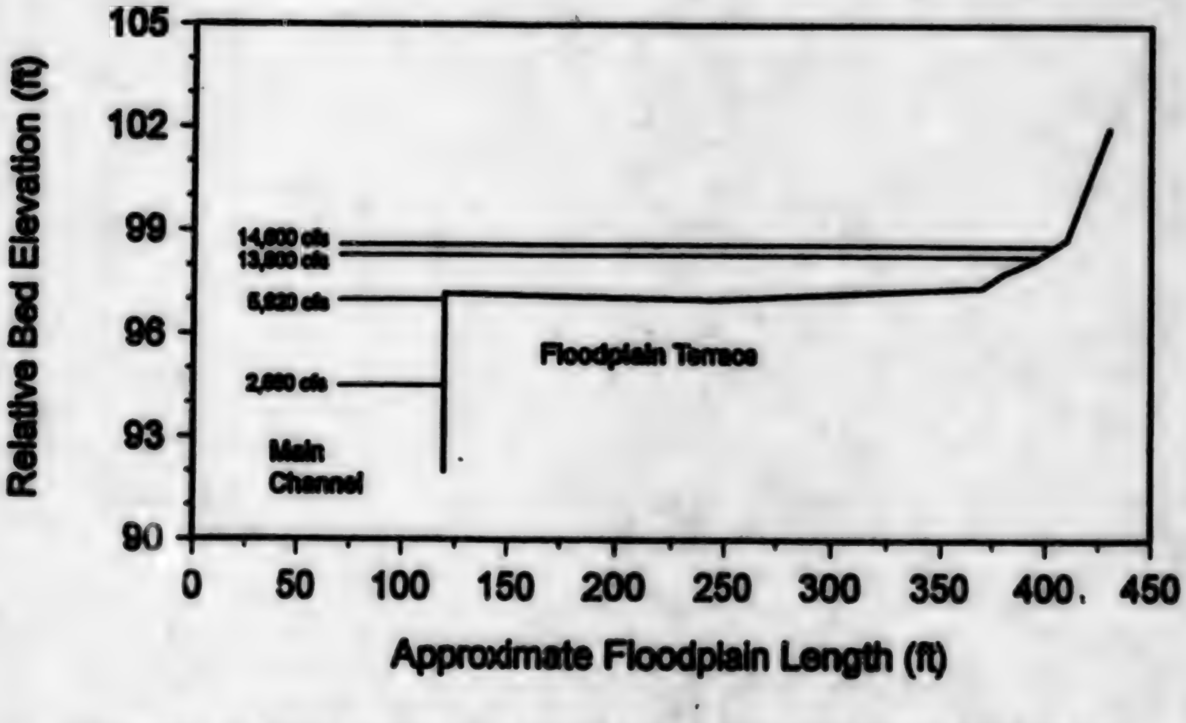

Figure 25. — Cross section of an oxbow of the Gunnison River at RM 52.3 in Escalante State Wildlife Area.

Discussion

Although differences in channel morphology at each study site dictated how they responded to changing river flows, there were similarities among all sites. Total surface area increased with increasing river flow at all study sites except Site 1, where the river was confined by high banks and the river could not expand as flows increased. Although fast run was present at all sites at all flows, it became increasingly dominant as discharge increased. This dominance was most pronounced at Site 1, where fast run composed 90 – 98% of available habitats at flows of 2,300 cfs and greater. The other study sites were more diverse and, although area of fast runs steadily increased as discharge increased, other habitats were always available in substantial amounts. At two study sites, fast run habitat (as a percentage of total area) decreased as flows rose high enough to flood low-lying areas. The dominance of fast runs at high flows was also noted by Carter et al. (1985) and Osmundson et al. (1995) . Although fast runs dominated, other habitats were always available to allow fish to escape the fast water in mid-channel habitats. Even at Site 1, flooded vegetation along the shore line provided quiet water where fish could escape the fast current.

Pool and slow run habitats were maximized at 981 cfs, the lowest flow studied, at all sites. Both habitats were available at 2,300 cfs, but their area decreased considerably at higher flows. Eddies and flooded vegetation became the most common low-velocity habitats at flows greater than 2,300 cfs. Osmundson et al. (1995) showed that Colorado squawfish preferred pools, eddies, and backwaters at moderate base flows and slow runs at very low base flows in the Colorado River. They used a combination of radio telemetry and a habitat-mapping study similar to this one to determine habitat preferences and habitat availability at different flows. They then used this data to recommend a base flow that maximized preferred habitats in the Colorado River between the Grand Valley Diversion and its confluence with the Gunnison River. The lowest flow measured during our study, 981 cfs, was the level that produced the largest area of pool and slow-run habitats at the five study sites. Qualitative observations made as the mapping team moved among study sites indicated that these habitats were available throughout the river and that habitat trends at the study sites generally reflected what was occurring in the river as a whole. Whether flows lower than 981 cfs would provide more or less preferred habitat was not determined. Slack water habitats (pools < 1.5 m deep) first appeared at 981 cfs. It is likely that shallow habitats like slack water would gradually replace pools as river flow continued to decrease. Based on radiotelemetry data, these shallow habitats are not used by Colorado squawfish (Osmundson et al. 1995). However, existing constraints on river management probably preclude flows from dropping much below this amount.

Under low flow conditions, Burdick (1997) recommended a minimum flow of 300 cfs below the Redlands Diversion Dam to provide aquatic habitat and a migration corridor between the Colorado River and the recently-constructed fishway at Redlands Dam. Added to the 750 cfs water right held by the Redlands Water and Power Company (Burdick 1997), this equates to a minimum flow of 1,050 cfs in the Gunnison River above the dam which approximates the 981-cfs flow assessed in our study. That flow provided the maximum amount of pool habitat along with a mixture of other habitats for endangered and other native fish above the diversion. In times of extremely low water availability, or during nonmigratory periods, it may be desirable to reduce river flows below 300 cfs downstream from the diversion to conserve water for release in spring. Redlands Water and Power Company has one of the most senior water rights on the Gunnison River which means that most, if not all, of their right will be met even during dry periods. That effectively provides a minimum flow of about 750 cfs in the Gunnison River during all but the driest years. Although habitat was not mapped at that flow, qualitative observations and cross-section data suggest that surface area of slack-water habitats would increase, but pool and slow-run habitats would still be available throughout the Gunnison River.

Water depth was also a consideration in minimum flows recommended by Burdick (1997) and Osmundson et al. (1995). Burdick's recommendations were made primarily to facilitate fish movement up and down the 2.3-mi section of the river downstream from Redlands Dam. He felt that a minimum of 1 ft of water was necessary to allow for Colorado squawfish movement up and down the river. Osmundson et al. recommended a minimum of 2.5 to 4 ft of water in pools depending on season and flow level. Both of these recommendations were met at all of our study sites at the lowest flow (981 cfs) examined. Some of the pools and slow runs were still quite deep at 981 cfs (4 – 8 ft deep). Interpretation of the cross-section data indicates that adequate water depth will also occur at 750 cfs. It is possible that migration could be restricted at a few shallow riffles, but fish should be able to move freely through most of the 50 mi of occupied habitat. Because 300 cfs provides 1 ft of depth in the channel downstream from Redlands Dam, it seems logical to assume that 750 cfs will provide more depth in portions of the river with equal width. River reaches that no longer provide adequate fish habitat at 750 cfs or that contain barriers restricting fish movement should be identified in the future.

No sites were mapped at discharges between 5,600 and 13,300 cfs. Rapidly fluctuating river flows resulted in mapping two similar discharges instead of capturing an intervening flow. Steep increases in habitat area at three of the study sites indicated that major changes occurred within that wide range, but it is impossible to distinguish the flow that caused the greatest increase. The inflection points for major habitat change at the other two sites were more clear. The steepest increase at Site 3 occurred between 4,500 and 5,500 cfs when several gravel bar-islands within the study area were covered. High, steep banks and cliffs confined the river as it increased in volume. As already mentioned, no appreciable increase in water surface area occurred at Site 1 because of high banks that confined the river at all flows studied.

Carter et al. (1985) believed that inflection points represent important habitat changes and often indicate river flows at or above bank-full discharge. Although not available in the habitat-mapping data, information on the flow that caused the largest change in habitat area at Site 5 (Escalante SWA) can be gained from staff gauge data. Habitat mapping at that site showed no flooded bottomland habitat at 5,600 cfs, but considerable flooded habitat at 13,000 cfs and higher. However, staff gauge data indicated that the old oxbow which provides the majority of bottomland habitat began to flood at flows just over 6,000 cfs. The water spread out considerably as it rose above that level, indicating that the major inflection point for Escalante SWA would be between flows of 6,000 – 7,000 cfs.

Staff-gauge data and observations made at the other two sites near Delta confirmed this general range of flows as important to creation of flooded bottomlands. Gauge data and general observations indicated that flooding of these important habitats occurred between about 6,000 and 8,000 cfs in several areas between Hartland Diversion and Escalante SWA. Obviously, floodplain habitat increased with increasing flows and there are site-specific differences, but considerable flooded habitat was available at flows between 6,000 and 8,000 cfs. The canyon-bound areas downstream from Escalante SWA had small, widely-scattered bottomlands that provide limited flooded habitats for native fishes. Two of the study sites in the canyon with potential bottomland habitats (sites 2, 3) required flows greater than 13,000 cfs before floodplain habitat became available.

Flooded bottomlands provide an important component of the Colorado River ecosystem and maintenance of these habitats is an important priority of the Recovery Program (Wydoski and Wick 1998; Nelson 1997). Flooded bottomlands provide resting areas and a more productive food source for young and adults of the endangered fishes as well as other native species. They are especially important to survival and growth of larval razorback suckers (Tyus and Karp 1990; Modde et al.1995; Modde 1996). Flow recommendations for the Gunnison River will have to provide flows sufficient to flood these bottomlands on a regular basis. Recommendations for timing, frequency, and duration of flooding should be based on life history requirements of razorback sucker.

The existing and potential floodplain habitat in the Delta area makes it the most logical place for channel modifications to restore availability of flooded bottomland habitats by levee removal. These modifications might increase the availability (both frequency and duration) of these important habitats in the flow regime that will result from reoperation of the Aspinall Unit. Irving and Burdick (1995) have already identified a number of sites near Delta that might be appropriate for floodplain enhancement, including the three sites monitored with staff gauges in our study (Confluence Park, Johnson Slough, and Escalante SWA). Also, Burdick (1994) described a conceptual plan for flooded bottomland management at two sites in Escalante SWA. Levee removal should begin in the Delta area as soon as funds become available.

Burdick (1995) recorded Colorado squawfish activity in and around study sites 1 and 2. He reported that 45 of 112 contacts with radio-tagged Colorado squawfish in the Gunnison River occurred within a 4-mi reach that included sites 1, 2, and 3. One contact occurred within Site 3, 8 contacts occurred within Site 2, and 15 contacts occurred within Site 1. He also captured two Colorado squawfish from a large eddy in Site 2 while electrofishing. Many of these contacts occurred during the presumed spawning period when several radio-tagged Colorado squawfish converged on a riffle area just upstream from Site 1. Although Site 3 was originally selected because it was thought to represent a potential spawning area, only one contact with a Colorado squawfish was ever made there and that was in early spring. Three contacts with radio-tagged Colorado squawfish were made in Site 4 and no contacts were made in Site 5, although contacts above and below indicated that two fish passed through the area.

Most contacts in Site 1 occurred when river flows were between 1,500 and 2,700 cfs (Burdick 1995). However, one fish was contacted there twice in a 2-wk period when flows ranged between 9,000 and 15,000 cfs. Even though the site was dominated by fast-run habitat, the Colorado squawfish was able to use the flooded vegetation along the shoreline as cover. Fish were also contacted at Site 2 during high flows (7,000 – 15,000 cfs) but a greater variety of low-velocity habitats were available there for the fish to use.

Many radio contacts in sites 1 and 2 were made during the presumed spawning period when several radio-tagged Colorado squawfish were located near a gravel bar between the two study reaches. As mentioned above, although Site 3 was picked because it was thought to represent spawning habitat, no Colorado squawfish were contacted in the reach during the presumed spawning period. Radio-tagged fish were dispersed over more than 30 mi of river during other parts of the year. Burdick (1995) did not record habitat-use data.

This study included two high-flow years and one low-flow year, with limited data collected in a second low-flow year. Highest mean-daily flows recorded during the study were 20,500 cfs in 1993, 6,040 in 1994, 17,300 in 1995, and 7,670 in 1996. Cross sections measured in 1993 – 1995 indicated that some channel modifications occurred in low-water years, but large changes occurred mainly during high runoff years. Some scouring or deposition happened in mid channel at all cross sections in all years. The river was not surveyed prior to the high-water year of 1993, so we can not tell what changes occurred during runoff that year. However, substantial bank erosion occurred at two study sites (4 and 5) during runoff in 1995. Qualitative observations at Site 3 showed that a large volume of gravel was shifted within the study site in 1995, but this shift was under represented on the bed profiles. More changes occurred in 1996, after surveying was completed. Two of the study sites were stable with no appreciable change recorded during the study.

Most cross sections were across riffles or runs, but one cross section was added to a pool at the upper end of Site 3 in 1994. Runoff scoured several feet of material out of the pool in 1995. Because the pool was not surveyed in 1993, we do not know whether the material built up in the pool during the low-runoff year of 1994, or whether high runoff in 1993 failed to move it. However, because the pool was scoured in 1995, it was probably also scoured in 1993 (because runoff exceeded that of 1995) and filled back in during 1994. Data collected by Milhous (in press) at Dominguez Flats (partially represented by Site 4 of this study) supports this conclusion: "The high flows of 1993 removed much of the fine sediment and scoured out the pools. The streamflows of 1994 started to fill in the pools but the high flow of 1995 ... removed the gravel deposited in 1994." Milhous (in press) calculated that a flow of 17,000 cfs was necessary to remove gravel from pools at Dominguez flats. Flows of that magnitude were reached in both 1993 and 1995. He indicated that a great deal of fine sediments and other materials had built up on the river bed during 7 years of low runoff prior to 1993. All of this material was removed in 1993. Osmundson et al. (1995) documented that backwaters and pools in the '15-mile reach' of the Colorado River filled in during low-runoff years and were scoured out during high-runoff years.

Conclusions

Relationship between area of fish habitat and river flow provide data that can assist with making flow recommendations for operation of the Aspinall Unit in the upper Gunnison River. A variety of habitats that vary among seasons are important to a diverse river system with healthy fish populations. These habitats fill a variety of needs depending on species, life stage and season. Any recommendations will involve providing a suite of flows to meet different needs during different parts of the year. Three conclusions, dealing with discrete times of the year, were reached that will assist with making those flow recommendations:

1. The lowest flow measured in this study was 981 cfs, which provided a mixture of pool and slow run habitats. This flow is consistent with flows (1,050 cfs) that occur in the Gunnison River when a minimum of 300 cfs is provided downstream from Redlands Diversion Dam to provide a migration

corridor between the dam and the Colorado River. This level approximates a base flow that will provide suitable habitat during late summer, fall and winter. Although not measured, the 750 cfs water right held by Redlands Water and Power Company may be adequate above the dam when the 300 cfs (or some portion thereof) is conserved for release at other times during dry years.

2. Spring flows of 6,000 – 8,000 cfs provide flooded-bottomland habitats near Delta, Colorado. Increasing flows provide more flooded habitats; however, low-velocity habitat was maximized at about 13,000 cfs in the primary floodplain study site. Flooded bottomlands are important for razorback suckers and other native species, and should be provided on a regular basis. Razorback sucker life history and other factors must be considered to determine how often and how long flows sufficient to provide these habitats should be provided.

3. Major channel modifications occurred more often in high-runoff years than in low-runoff years. Periodic high flows that re-configure the channel and floodplain are necessary to maintain habitat complexity in the Gunnison River.

Recommendations

1. The habitat relationships described here should be used in conjunction with data collected during other studies and basic life-history information for the four endangered fishes to make flow recommendations for the Gunnison River.

2. Any flow recommendations implemented for the Gunnison River should be accompanied by a monitoring program to assess the results. The evaluation should include options for monitoring channel change and area of floodplain habitat, as well as responses by the native fish community.

3. Levee removal should begin in the Delta area as soon as funds become available.

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Appendix A

Table A-1. — Definitions of macro habitat types used in the Gunnison River (modified slightly from Osmundson et al. 1995).

Habitat Type	Description
Fast Run (FRU)	A stretch of relatively swift-moving water (> 2.0 ft/sec) with a laminar or slightly broken surface. Water depth is usually > 2.0 ft.
Slow Run (SRU)	A stretch of moving water with a noticeable downstream current (> 0.4 but < 2 ft/sec) with a laminar surface. Water depth is usually > 2.0 ft.
Rapid (RA)	The water surface is broken into waves by steep gradient or obstructions wholly or partly submerged under the water surface. The water column is > 1.0 ft deep.
Riffle (RI)	The water surface is broken into small waves in areas of shallow water. Water is less than 1 ft deep and often much shallower. Smaller waves and shallower water differentiate riffles from rapids.
Eddy (ED)	Areas where the dominant current moves upstream or in a whirlpool fashion. Usually formed where obstacles in the channel or along the shoreline alter the main flow of the river.
Pool (PO)	Quiet areas in the main channel with slow, but perceptible flow, < 0.4 ft/sec. Depth > 1.5 ft.
Slack water (SLK)	Shallow, quiet areas in the main channel or along shorelines with no or very slow flow (< 0.4 ft/sec). Depth < 1.5 ft.
Backwater (BA)	Quiet water with no perceptible flow. Often formed when the upstream end of a side channel is cut off during low flow. Also includes indentations in the river bank or flooded mouths of tributaries.
Sheet Flow (SHT)	Areas outside of the main river channel inundated by high water. Water is generally shallow and moving downstream at a moderately fast to fast velocity. Often has a variety of micro habitats due to different depths and water velocities that could not be mapped.
Flooded Vegetation (FV)	Vegetation inundated by rising water, usually along the shoreline of the main river channel. Velocity was often substantially lower than immediately outside of the vegetation. Also included vegetated areas outside of the main channel inundated at high water.
Flooded Bottomland (FB)	Areas outside of the main river channel inundated by high water. Differentiated from sheet flow by lower water velocity and greater depth. Overlaps to some degree with flooded vegetation. This category was primarily delineated on the video after the flight because the large area was impossible to map from the ground.

Appendix B

Table B-1. — Total surface area of 13 habitat types measured at 6 different river flows at Study Site 1, RM 31.8 – 32.4.

	Total Surface Area (m^2) by River Flow (cfs)					
Habitat Type	981	2,300	4,500	5,560	13,300	15,800
Fast Run	2,622	61,544	67,387	68,829	69,467	70,190
Slow Run	53,418					
Rapid						
Riffle	2,611	300				
Eddy	1,103	3,393			133	484
Pool	3,012					
Slackwater		544				
Backwater	338					
Sheet Flow						
Flooded Vegetation		649	1,307	1,300	1,305	1,296
Flooded Bottomland						

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Table B-2. — Total surface area of 13 habitat types measured at 6 different river flows at Study Site 2, RM 33.6 – 34.1.

	Total Surface Area (m^2) by River Flow (cfs)					
Habitat Type	981	2,300	4,500	5,560	13,300	15,800
Fast Run	2,756	18,412	34,025	29,619	36,097	38,444
Slow Run	14,013	8,438		2,014	362	
Rapid	1,089	284	891	2,909	4,467	1,336
Riffle	1,260	1,519	253			
Eddy	8,000	3,545	4,816	5,948	7,060	6,896
Pool	8,887	5,024	125			
Slackwater				548	165	9,696
Backwater	739		10	93		89
Sheet Flow						
Flooded Vegetation					612	960
Flooded Bottomland						

Table B-3. — Total surface area of 13 habitat types measured at 6 different river flows at Study Site 3, RM 34.3 – 34.9.

Habitat Type	Total Surface Area (m^2) by River Flow (cfs)					
	981	2,300	4,500	5,560	13,300	15,800
Fast Run	20,061	27,048	44,096	42,288	77,912	87,345
Slow Run	17,646	4,985	6,038	6,713	4,038	
Rapid	1,319	1,233	3,654	3,154	1,936	1,416
Riffle	4,104	13,162	7,843	10,423	1,242	1,946
Eddy	1,757	2,173	1,842	3,999	2,915	3,213
Pool	3,466	8,050				
Slackwater	2,983		1,221	763	950	
Backwater	32	291	1,368	213		167
Sheet Flow					8,512	11,261
Flooded Vegetation				1,467	828	1,436
Flooded Bottomland						

Table B-4. — Total surface area of 13 habitat types measured at 6 different river flows at Study Site 4, RM 37.4 – 38.3.

	Total Surface Area (m²) by River Flow (cfs)					
Habitat Type	981	2,300	4,500	5,560	13,300	15,800
Fast Run		41,212	66,138	92,210	103,709	112,760
Slow Run	40,625	16,921	4,468	3,806	3,297	
Rapid	840	3,671	495	1,486		
Riffle	11,457	5,380	3,989	390		
Eddy	2,537	1,598	2,549	2,411	2,581	1,946
Pool	3,968	706				341
Slackwater	5,934	2,103	617	785	199	
Backwater	1,238		2,026			
Sheet Flow						3,815
Flooded Vegetation	120	110	1,284	7,857	9,402	5,743
Flooded Bottomland						

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Table B-5. — Total surface area of 13 habitat types measured at 6 different river flows at Study Site 5, RM 50.7 – 52.3.

	Total Surface Area (m^2) by River Flow (cfs)					
Habitat Type	**981**	**2,300**	**4,500**	**5,560**	**13,300**	**15,800**
Fast Run	53,203	104,106	136,312	112,559	207,222	165,305
Slow Run	45,748	27,596	21,752	53,888	35,251	33,194
Rapid		747	500		1,525	5,806
Riffle	9,601	23,189	14,000	13,276	11,691	44,004
Eddy	6,166	15,851	10,282	9,138	12,053	3,020
Pool	2,024	9,416	4,345	2,728	4,348	
Slackwater	3,069	1,385	4,917	4,810	40,908	
Backwater	2,510	6,809	7,300	8,374	1,921	
Sheet Flow					107,312	321,910
Flooded Vegetation				4,990	49,854	58,100
Flooded Bottomland					54,870	56,968

END

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